METHODS FOR ALTERING HEMATOPOIETIC PROGENITOR CELL ADHESION, DIFFERENTIATION , AND MIGRATION

This application claims priority to co-pending U.S. Provisional Application Serial No. 60/507,202, filed September 29, 2003, the contents of which are incorporated herein in their entirety.

This invention was made, in part, with government support under grant numbers CA71619, and CA 83133 awarded by the National Cancer Institute of the National Institutes of Health. The U.S. government has certain rights in the invention.

FIELD OF THE INVENTION

The invention relates to methods for altering hematopoietic progenitor cell (such as hematopoietic stem cell and endothelial progenitor cell) adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell. The invention also relates to methods for screening test compounds for altering the level of hematopoietic progenitor cell adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell. The invention further relates to methods for isolating hematopoietic progenitor cells.

BACKGROUND OF THE INVENTION

Hematopoietic progenitor cells (such as bone marrow derived, CD34+ stem cells) promote the repair of diseased and damaged tissues and offer promise for the treatment of hereditary and acquired human diseases (Asahara et al. (1997) Science 275, 964-967; Rafii et al. (2003) Nat. Med. 9, 702-12; Takahashi et al. (1999) Nat. Med. 5,434-438; Kawamoto et al. (2001) Circulation 103, 634-637; Hattori et al. (2001) J. Exp. Med. 193, 1005-1014; Otani et al. (2002) Nat. Med. 8, 1004-1010 (2002); Priller (2001) et al. J. Cell Biol. 155, 733-738; LaBarge et al. (2002) Cell. 111, 589-601; and Torrente et al. (2003) J. Cell Biol. 162, 511-520). For example, bone marrow derived, CD34+ stem cells promote neovascularization by differentiating into endothelial cells (Asahara et al. (1997) supra; Rafii et al. (2003) Nat. Med. 9, 702-12; Takahashi et al. (1999) Nat. Med. 5,434-438; Kawamoto et al. (2001) Circulation 103, 634-637; Hattori et al. (2001) J. Exp. Med. 193, 1005-1014; Otani et al. (2002) Nat. Med. 8, 1004-1010 (2002); Priller (2001) et al. J. Cell Biol. 155, 733-738; LaBarge et al. (2002) Cell. 111, 589-601; Torrente et al. (2003) J. Cell Biol. 162, 511-520); Lyden et al. (2001) Nat. Med. 7, 1194-201; Ruzinova et al. (2003) Cancer Cell. 4: 277-289; Jain et al. (2003) Cancer Cell 3, 515-516; Religa et al. (2002) Transplantation 74, 1310-1315; and Boehm et al. (2004) J. Clin. Invest. 114, 419-426). Although neovascularization stimulates healing of injured tissue (Asahara et al. (1997)

supra; Rafii et al. (2003) Nat. Med. 9, 702-12; Takahashi et al. (1999) Nat. Med. 5,434-438; Kawamoto et al. (2001) Circulation 103, 634-637; Hattori et al. (2001) J. Exp. Med. 193, 1005-1014; Otani et al. (2002) Nat. Med. 8, 1004-1010 (2002); and Carmeliet (2003) Nat. Med. 9, 653-660), it nonetheless also promotes undesirable consequences such as tumor growth and inflammatory disease (Lyden et al. (2001) Nat. Med. 7, 1194-201; Ruzinova et al. (2003) Cancer Cell. 4: 277-289; Jain et al. (2003) Cancer Cell 3, 515-516; Carmeliet (2003) Nat. Med. 9, 653-660; and Hanahan et al. (1996) Cell 86, 353-364).

While the art appreciates some of the advantages of using hematopoietic progenitor cells, it remains unclear how hematopoietic progenitor cell adhesion, differentiation, and migration may be modulated. Thus, there remains a need for methods for altering hematopoietic progenitor cell adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell.

SUMMARY OF THE INVENTION

The present invention satisfies the need in the art by providing methods for altering hematopoietic progenitor cell (HPC) adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell. The invention also provides methods for screening test compounds for altering the level of hematopoietic progenitor cell adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell. The invention further provides methods for isolating hematopoietic progenitor cells.

In particularly preferred embodiments, the invention provides a method for altering the level of hematopoietic progenitor cell adhesion to target tissue, comprising: a) providing: i) a population of cells comprising hematopoietic progenitor cells that express integrin $\alpha4\beta1$, ii) target tissue that is not bone marrow endothelial tissue, and iii) one or more agent that alters specific binding of integrin $\alpha4\beta1$ to an integrin $\alpha4\beta1$ ligand, and b) treating one or more of the population of cells and the target tissue with the agent under conditions for specific binding of the integrin $\alpha4\beta1$with the integrin $\alpha4\beta1$ ligand, thereby altering the level of adhesion of the hematopoietic progenitor cells to the target tissue. In one embodiment, the treating further comprises altering the level of trans-endothelial migration of the hematopoietic progenitor cells. In another embodiment, the treating further comprises altering the level of differentiation of the hematopoietic progenitor cells into a second cell, such as when compared to adjacent normal tissues and/or to other normal organs (*e.g.*, Examples 22-23, and Figure 36a-b). In another embodiment, the treating does not comprise altering the level of angiogenesis in the target tissue.

While not intending to limit the type or source of HPCs, in one embodiment, the HPCs may be transgenic or wild type. In another embodiment, the HPCs comprise CD34+

non-endothelial cells and/or CD34+CD133+ cells which can differentiate into endothelium (Figure 34a). In a further embodiment, the HPCs comprise one or more of hematopoietic stem cell, endothelial progenitor cell, lymph endothelial progenitor cell, mesenchymal precursor cell, myeloid progenitor cell, lymphoid progenitor cell, granulocyte progenitor cell, macrophage progenitor cell, megakaryocyte progenitor cell, erythroid progenitor cell, Pro-B cell and Pro T cell, bone marrow progenitor cell, peripheral blood progenitor cell, umbilical cord progenitor cell, CD34+ progenitor cell comprised in any tissue (such as lung tissue, breast tissue, prostate tissue, cervical tissue, pancreatic tissue, colon tissue, ovarian tissue, stomach tissue, esophageal tissue, mouth tissue, tongue tissue, gum tissue, skin tissue, muscle tissue, heart tissue, liver tissue, bronchial tissue, cartilage tissue, bone tissue, testis tissue, kidney tissue, endometrium tissue, uterus tissue, bladder tissue, bone marrow tissue, lymphoma tissue, spleen tissue, thymus tissue, thyroid tissue, brain tissue, neuron tissue, gall bladder tissue, ocular tissue (*e.g.*, the cornea, uvea, choroids, macula, vitreous humor, *etc.*), and joint tissue (*e.g.*, synovium tissue, *etc.*). In one embodiment, the bone marrow progenitor cells comprise one or more of CD31+ cells (Example 24, Figure 36e-f), cKit+ cells, VEGFR1+ cells, VEGFR2+ cells, and CD34+ cells.

The invention is not intended to be limited to the type or source of target tissue. Nonetheless, in one embodiment, the target tissue comprises one or more of vascular endothelial, muscle, neuronal, tumor, inflammatory, peripheral blood, cord blood, heart, ocular, skin, synovial, tumor, lung, breast, prostate, cervical, pancreatic, colon, ovarian, stomach, esophageal, mouth, tongue, gum, skin, liver, bronchial, cartilage, testis, kidney, endometrium, uterus, bladder, spleen, thymus, thyroid, brain, neuron, gall bladder, ocular, and joint tissues. In a preferred embodiment, the tissue is injured, ischemic and/or malignant (such as metastatic malignant tumor tissue). In another embodiment, the target tissue comprises one or more of fibronectin and vascular tissue. In a preferred embodiment, the vascular tissue comprises one or more cell types such as endothelial cells, pericyte cells, vascular smooth muscle cells, angiogenic tissue, and tissue that is not angiogenic.

The invention is not intended to be limited to the source or type of second cell into which the HPC differentiates. In one embodiment, the second cell type comprises a mesenchymal cell precursor and/or mesenchymal cell, such as, without limitation, one or more of fibroblast cell, myofibroblast cell, stromal cell, pericyte cell, vascular smooth muscle cell, and endothelial cell. In another embodiment, the second cell type comprises an epithelial cell, such as one or more of epidermal cell, secretory cell, hair cell, cornea cell, hepatocyte cell, alveolar cell, pneumocyte cell, skin cell, intestinal cell, and renal cell. In a preferred embodiment, the secretory cell is chosen from one or more of mammary epithelial cell, intestinal cell, and sebaceous epithelial cell, and the hair cells is chosen from one or more of ear hair cell and skin hair cell. In a further embodiment, the second cell type

comprises a muscle cell precursor and/or muscle cell such as, without limitation, one or more of skeletal muscle myocyte cell, cardiac myocyte cell, vascular smooth muscle cell, endocardium cell, and myocardium cell. In yet another embodiment, the second cell type comprises a neuronal cell precursor and/or neuronal cell such as, without limitation, one or more of astrocyte cell, Schwann cell, Purkinje cell, dendritic cell, and glial cell. In another embodiment, the second cell type comprises an immune cell precursor and/or immune cell such as one or more of B lymphocyte cell, T lymphocyte cell, monocyte/macrophage cell, granulocyte cell, eosinophil cell, neutrophil cell, natural killer cell, and megakaryocyte cell, wherein the monocyte cell is exemplified, but not limited to, one or more of macrophage cell, osteoclast cell and osteoblast cell. In yet a another embodiment, the second cell type comprises an embryonic cell precursor, an embryonic cell, a melanocyte cell precursor, melanocyte cell, myoepithelial cell precursor and/or a myoepithelial cell such as those found in glandular tissues.

The invention is not limited to the location of treatment of the HPCs and target tissue with the agent. In one embodiment, the treating may be *in vitro* (Examples 19, 20), *ex vivo*, and *in vivo* in a mammalian subject (Example 21). In a preferred embodiment, the mammalian subject is chosen from one or more of a subject that has a disease, is susceptible to having a disease, is suspected of having a disease, and is suspected of being susceptible to having a disease. More preferably, the treating is chosen from one or more of before, during, and after manifestation of one or more symptoms of the disease. In one preferred embodiment, the mammalian subject is human.

In one embodiment, the disease is angiogenic, such as, without limitation, one or more of neoplasm, diabetic retinopathy, macular degeneration associated with neovascularization, psoriasis hemangiomas, gingivitis, rheumatoid arthritis, osteoarthritis, inflammation, and inflammatory bowel diseases. While not intending to limit the target tissue in the subject, in one embodiment, the tissue comprises one or more of ocular tissue, skin tissue, bone tissue, and synovial tissue, wherein the ocular tissue is exemplified by retina, macula, cornea, choroids, and vitreous humor. In another embodiment, the tissue comprises a tumor, such as a malignant tumor, and more preferably a metastatic malignant tumor.

In another embodiment, the disease is not angiogenic. In some embodiments, it may be desirable to reduce adhesion of HPCs to a target tissue in non-angiogenic diseases such as in diseases that are exemplified by, but not limited to, fibrosis (wherein hematopoietic progenitor cells differentiate into fibroblasts or other cells in the exemplary tissues of lung, liver cardiac, skin, and/or cornea cells), atherosclerosis (wherein hematopoietic progenitor cells differentiate into the exemplary macrophages/monocytes, vascular smooth muscle cells, and/or endothelial cells in a blood vessel wall), restenosis (wherein hematopoietic

progenitor cells differentiate into vascular smooth muscle cells, immune cells such as monocytes/macrophages, eosinophils, granulocytes and/or to other immune cells in a blood vessel wall), chronic inflammatory diseases such as rheumatoid arthritis (wherein hematopoietic progenitor cells differentiate into endothelial cells, pericytes, and/or synoviocytes, which digest cartilage, monocytes/macrophages which secrete angiogenic and inflammatory factors), asthma (wherein hematopoietic progenitor cells differentiate into eosinophils and their immune cells, endothelial cells, pericytes, and/or fibroblasts), cancer (wherein hematopoietic progenitor cells differentiate into malignant cells and/or stromal cells such as fibroblasts, endothelial cells, smooth muscle cells, and/or monocytes, *etc.*), whether or not the cancer is metastatic, myocardial infarction (wherein hematopoietic progenitor cells differentiate into inflammatory cells arising from hematopoietic stem cells and/or fibroblasts arising from hematopoietic stem cells), and ischemic disease, such as hemorrhagic stroke (brain), acute respiratory disorder, myocardial infarction, peripheral artery disease (inhibit inflammatory cells that arise from hematopoietic stem cells).

In another embodiment, it may be desirable to increase adhesion of HPCs to a target tissue in non-angiogenic diseases such as in a subject that has undergone bone marrow transplantation and a subject that will undergo bone marrow transplantation, wherein the treating is chosen from one or more of before, during, and after the bone marrow transplantation. In another embodiment, the mammalian subject is chosen from a subject that has undergone hematopoietic progenitor cell transplantation and a subject that will undergo hematopoietic progenitor cell transplantation, wherein the treating is chosen from one or more of before, during, and after the hematopoietic progenitor cell transplantation. In yet a further embodiment, the mammalian subject has and/or is susceptible to developing a wound to a tissue (wound healing of all types including, but not limited to, burns, skin wounds, surgical wounds to any tissue and organ including cosmetic surgery and internal surgery, scar replacement, myocardial infarction (the invention is useful to repair tissues by stimulating blood vessel growth, epithelial tissue repair by re-growth, and cardiac myocytes development), severed nerves (*e.g.*, involving neuronal cells and endothelial cells of any type), injured brain (*e.g.*, involving neuronal cells and endothelial cells), injured muscle (*e.g.*, involving myocytes and endothelial cells), congenitally damaged muscle as in muscular dystrophy- Duchenne and other diseases involving skeletal myocytes, peripheral artery ischemia disease (PAD) (the invention is useful for stimulating homing by, adhesion by, and differentiation of hematopoietic progenitor cells to muscle cells, neuronal cells, endothelial cells, pericytes, and/or vascular smooth muscle), stroke (the invention is useful for stimulating homing by, adhesion by, and differentiation of hematopoietic progenitor cells to neuronal cells and/or vascular cells), Parkinson's disease (the invention is useful for stimulating homing by, adhesion by, and differentiation of hematopoietic progenitor cells

into cells that produce serotonin). In another embodiment, the mammalian subject has diabetes and/or is susceptible to developing diabetes (the invention is useful for stimulating homing by, adhesion by, and differentiation of hematopoietic progenitor cells into pancreatic islet cells, which are the source of insulin). In a further embodiment, the mammalian subject has and/or is susceptible to developing AIDS (the invention is useful for stimulating homing by, adhesion by, and differentiation of hematopoietic progenitor cells to T-cells to stimulate T-cell repopulation of tissues). In another embodiment, the mammalian subject has and/or is susceptible to developing cancer (the invention is useful for stimulating homing by, adhesion by, and differentiation of hematopoietic progenitor cells to cancer fighting immune cells such as T cells and natural killer cells .

The invention is not intended to be limited to a particular type or source of agent that alters HPC adhesion and/or migration to a target tissue, and that alters HPC differentiation into a second cell type. In one embodiment, the agent comprises a peptide, such as an antibody as exemplified by, but not limited to, an antibody that comprises an anti-integrin $\alpha4\beta1$ antibody (*e.g.*, Examples 19-21, Figures 34b, d-e, and 35b-d). In one embodiment, the specificity of binding of the anti-integrin $\alpha4\beta1$ antibody may be compared to a control antibody such as anti-$\beta2$ integrin antibody (Example 24), cIgG antibody (Example 24), anti-$\alpha v\beta5$ (P1F6), and anti-$\alpha5\beta1$ (P1F6) (Figures 17-20 and 34) and anti-$\alpha v\beta3$ (LM609) (Figure 20). In another embodiment, the comprises one or more of an anti-vascular cell adhesion molecule antibody, and an anti-fibronectin antibody. In another embodiment, the agent comprises an antisense sequence, such as, without limitation, an antisense sequence that comprises one or more of an integrin $\alpha4\beta$ 1 antisense sequence, a vascular cell adhesion molecule antisense sequence, and a fibronectin antisense sequence. In yet another embodiment, the agent comprises a ribozyme such as, without limitation, a ribozyme that comprises an integrin $\alpha4\beta1$ ribozyme, a vascular cell adhesion molecule ribozyme, and a fibronectin ribozyme. While the invention is not limited to the mechanism of action of the agent, in one embodiment, the agent may function by one or more of a) inducing expression of $\alpha4\beta1$ on HPCs; b) activating $\alpha4\beta1$ on HPCS such as by increasing the level of specific binding of integrin $\alpha4\beta1$ to one or more of its ligands, and c) inducing expression of one or more $\alpha4\beta1$ ligand by the one or more cell type.

It is also not intended that the invention be limited to any particular type or source of integrin $\alpha4\beta1$ ligand. In one preferred embodiment, the ligand comprises one or more of vascular cell adhesion molecule (VCAM) and fibronectin.

The invention additionally provides a method for altering the level of hematopoietic progenitor cell trans-endothelial migration to target tissue, comprising: a) providing: i) a population of cells comprising hematopoietic progenitor cells that express integrin $\alpha4\beta1$, ii) target tissue that is not bone marrow endothelial tissue, and iii) one or more agent that alters

specific binding of integrin $\alpha4\beta1$ to an integrin $\alpha4\beta1$ ligand, and b) treating one or more of the population of cells and the target tissue with the agent under conditions for specific binding of the integrin $\alpha4\beta1$with the integrin $\alpha4\beta1$ ligand, thereby altering the level of trans-endothelial migration of the hematopoietic progenitor cells to the target tissue. In one embodiment, the treating does not comprise altering the level of angiogenesis in the tissue to which the hematopoietic progenitor cells migrate.

Additionally provided herein is a method for altering the level of hematopoietic progenitor cell differentiation into a second cell type that is not a bone marrow endothelial cell, comprising: a) providing: i) a population of cells comprising hematopoietic progenitor cells that express integrin $\alpha4\beta1$, and ii) one or more agent that alters specific binding of integrin $\alpha4\beta1$ to an integrin $\alpha4\beta1$ ligand, and b) treating the population of cells with the agent under conditions for specific binding of the integrin $\alpha4\beta1$with the integrin $\alpha4\beta1$ ligand, thereby altering the level of differentiation of the hematopoietic progenitor cell into the second cell type. In one embodiment, the treating does not comprise altering the level of angiogenesis in the tissue in which the hematopoietic progenitor cells differentiate.

The invention also provides a method for screening a test compound for altering the level of hematopoietic progenitor cell adhesion to target tissue that is not bone marrow endothelial tissue, comprising: a) providing: i) a first composition comprising integrin $\alpha4\beta1$, ii) a second composition comprising one or more integrin $\alpha4\beta1$ ligand, and iii) a test compound, b) contacting the test compound with one or more of the first composition and the second composition under conditions for specific binding of the integrin $\alpha4\beta1$with the integrin $\alpha4\beta1$ ligand, and c) detecting an altered level of specific binding of the integrin $\alpha4\beta1$with the integrin $\alpha4\beta1$ ligand in the presence of the test compound compared to in the absence of the test compound, thereby identifying the test compound as alerting the level of hematopoietic progenitor cell adhesion to the target tissue. In one embodiment, the method further comprises identifying the test compound as altering the level of one or more of migration of the hematopoietic progenitor cells, and of differentiation of the hematopoietic progenitor cells into a second cell type. Changes in the levels of migration and differentiation may be compared to control adjacent normal tissues or to other normal organs (*e.g.*, Example 22 such as inhibition of HPC differentiation as exemplified in Example 23, Figure 36a-b). The contacting is not limited to any particular location, but may be *in vitro* (Examples 19, 20), *ex vivo*, and *in vivo* in a non-human mammal (Example 21).

The invention additionally provides a method for screening a test compound for altering the level of hematopoietic progenitor cell trans-endothelial migration to a tissue that is not bone marrow endothelial tissue, comprising: a) providing: i) a first composition comprising integrin $\alpha4\beta1$, ii) a second composition comprising one or more integrin $\alpha4\beta1$ ligand, and iii) a test compound, b) contacting the test compound with one or more of the

first composition and the second composition under conditions for specific binding of the integrin α4β1with the integrin α4β1 ligand, and c) detecting an altered level of specific binding of the integrin α4β1with the integrin α4β1 ligand in the presence of the test compound compared to in the absence of the test compound, thereby identifying the test compound as alerting the level of hematopoietic progenitor cell trans-endothelial migration to the tissue.

Also provided by the invention is a method for screening a test compound for altering the level of hematopoietic progenitor cell differentiation into a second cell type that is not a bone marrow endothelial cell, comprising: a) providing: i) a first composition comprising integrin α4β1, ii) a second composition comprising one or more integrin α4β1 ligand, and iii) a test compound, b) contacting the test compound with one or more of the first composition and the second composition under conditions for specific binding of the integrin α4β1with the integrin α4β1 ligand, and c) detecting an altered level of specific binding of the integrin α4β1with the integrin α4β1 ligand in the presence of the test compound compared to in the absence of the test compound, thereby identifying the test compound as alerting the level of hematopoietic progenitor cell differentiation into the second cell type.

The invention additionally provides a method for isolating hematopoietic progenitor cells from a tissue, comprising: a) providing: i) a tissue comprising hematopoietic progenitor cells, ii) an antibody that specifically binds to integrin α4β1 polypeptide, b) treating the tissue with the agent under conditions such that the antibody binds to the hematopoietic progenitor cells, and c) isolating the hematopoietic progenitor cells that bind to the antibody.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the polypeptide sequence (SEQ ID NO:1) of the human α4 subunit, GenBank Accession No. XP_039012.1.

Figure 2 shows the polypeptide sequence (SEQ ID NO:2) of the human β1 subunit, GenBank Accession No. P05556.

Figure 3 shows the polypeptide sequence of the human vascular cell adhesion molecule (VCAM), GenBank Accession Nos. P19320 (SEQ ID NO:3) (A) and XP_035774 (SEQ ID NO:96) (B).

Figure 4 shows the polypeptide sequence (SEQ ID NO:4) of human fibronectin, GenBank Accession No. P02751.

Figure 5 shows exemplary agents which inhibit binding of integrin α4β1 to VCAM.

Figure 6 shows exemplary agents which inhibit binding of integrin α4β1 to its ligands, with IC50 values based on direct binding assays. In this Figure, the abbreviations

are as follows: FCA, 9-fluorenecarboxyl; IC, inhibition concentration; PA, phenylacetyl.

Figure 7 shows exemplary β-turn mimetics which inhibit binding of integrin α4β1 to fibronectin.

Figure 8 shows the cDNA sequence (SEQ ID NO:5) of the human integrin α4 subunit cDNA, GenBank Accession No. XM_039012.

Figure 9 shows the cDNA sequence (SEQ ID NO:6) of the human integrin α4 subunit, GenBank Accession No. XM_039012.

Figure 10 shows the cDNA sequence (SEQ ID NO:7) of the human integrin β1 subunit, GenBank Accession No. X07979.

Figure 11 shows the human VCAM cDNA sequence (SEQ ID NO:8), GenBank Accession No. X53051.

Figure 12 shows the sequence of human fibronectin cDNA (SEQ ID NO:9), GenBank Accession No. X02761.

Figure 13 shows a graph of percent cells expressing integrin α4β1 versus human umbilical vein endothelial cells (HUVEC) and endothelial progenitor cells (EPCs).

Figure 14 shows a graph of number of beta-galactosidase positive cells per 100X field versus antibody treatments (Panel A) and photographs of immunostained cryosections of excised matrigel plugs (Panel B).

Figure 15 shows that integrin α4β1 and CS-1 fibronectin regulate angiogenesis. (A) Blood vessel branchpoints at 30X magnification in CAMs stimulated with 1 μg/ml bFGF and treated with anti-fibronectin CBP or CS-1 function-blocking or control antibodies. (B) Blood vessel branchpoints in bFGF, VEGF, TNFα, or IL-8 stimulated CAMs treated saline, anti-integrin α4β1 (HP1/2) or control isotype matched antibodies. (C) Angiogenesis was initiated in FVB/N mice by subcutaneous injection growth factor reduced matrigel supplemented with bFGF or VEGF, and mice (n=8) were treated by i.v. injection of rat anti-integrin α4β1 (PS/2) (white bars) or isotype-matched control antibodies (rat anti-integrin β2) (black bars). Microvessel density was quantified at 200X by CD31 immunohistochemistry (right). (D-E) HT29 human α4β1 negative colon carcinoma cells were implanted subcutaneously in nude mice (n=10) and mice with palpable tumors (about 30 mm^3) were treated by i.v. injection of saline, rat-anti-mouse α4β1 or isotype matched control antibody, anti-CD11b integrin. (D) Mean tumor mass +/- SEM. (E) CD31 positive microvessels were detected by immunohistochemistry and quantified per 200X field.

Figure 16 shows expression of α4β1 on endothelial cells and endothelial precursor cells. (A) Five micron thick cryosections of human lymph node, melanoma and invasive ductal breast carcinoma were immunostained with anti-vWF (green) antibodies and P1H4, an anti-human α4β1 (red) antibody. (B) Five micron thick cryosections of human breast carcinoma, murine MTAG spontaneous breast carcinoma, murine VEGF matrigel, normal

murine liver, bFGF stimulated CAM and normal CAM were immunostained with anti-vWF (red) antibodies and goat anti-alpha 4 cytoplasmic tail (green) antibody. Concordance of expression is indicated by yellow. C) FACs analysis of HMVECs for CD31 and $\alpha4\beta1$ expression. (D) FACs analysis of expression levels in EPCs at day 4 and day 7 of CD34, AC133, and Flk-1. (E) FACs analysis of expression levels in EPCs at day 4 and day 7 of CD31, VE-Cadherin, VCAM, and VWF. (F) FACs analysis of expression levels in EPCs at day 4 and day 7 of beta 1, beta 7, beta 2, $\alpha4\beta1$, $\alpha v\beta3$, $\alpha v\beta5$ and $\alpha5\beta1$. (G) Micrographs under transmitted light of EPCs at 4, 7 or 9 days in culture.

Figure 17 shows functional roles of EPC expressed $\alpha4\beta1$. (A-B) Adhesion of purified EPCs on plastic plates coated with (A) 5 µg/ml CS-1 fibronectin or (B) recombinant soluble VCAM in the presence of medium, anti-$\alpha4\beta1$ (HP1/2) or control antibodies (P1F6). (C) Adhesion of DiI-labeled purified EPCs to HUVEC monolayers VCAM in the presence of medium, anti-$\alpha4\beta1$ (HP1/2) or control antibodies (P1F6). Cells were quantified by counting adherent red fluorescent cells per 200X microscopic field. (D) Adhesion of DiI-labeled purified EPCs to HUVEC monolayers in the presence of medium, rsVCAM or control protein. Statistical significance was determined using Student's t-test.

Figure 18 shows integrin $\alpha4\beta1$ controls endothelial precursor cell trafficking *in vivo*. (A) DiI acetylated-LDL (red) labeled endothelial progenitor cells were mixed in growth factor depleted matrigel with 400 ng/ml VEGF, no antibody, control antibody (P1F6) or anti-human $\alpha4\beta1$ antibody (HP1/2). After 5 days, mice were injected with Bandeira simplicifolia lectin-FITC (green) and sacrificed. Cryosections were analyzed by fluorescence microscopy. (B) DiI acetylated-LDL labeled endothelial progenitor cells were injected i.v. into animals bearing 200 mm3 HT29 colon carcinoma tumors together with no antibody, control antibody (P1F6) or anti-human $\alpha4\beta1$ antibody (HP1/2). After 5 days, mice were injected with Bandeira simplicifolia lectin-FITC and sacrificed. Cryosections were analyzed by fluorescence microscopy. (C-D) Tie2LacZpositive bone marrow was transplanted into irradiated FVB/N mice. After one month of recovery, angiogenesis was with bFGF (B) or VEGF (C) and mice were treated by i.v. injection with rat anti-mouse $\alpha4\beta1$ (PS/2) or isotype matched control (anti-b2 integrin) antibody (n=8). Cryosections were treated to detect expression of beta galactosidase within the matrigel plugs (200X); inset, 600X. Mean +/- S.E.M. of Lac Z positive cells per 200X field was determined. (E) LacZ positive cells were detected within vessels by immunostaining for beta-galactosidase (green) and for CD31 (red) expression at 200X. Vessels positive for both are yellow (arrows). (F) Mean +/- S.E.M. LacZ+ CD31+ vessels (n=8). Statistical significance was determined using Student's t-test.

Figure 19 shows (A) Migration of endothelial cells on 8 µm pore transwells coated with 5 µg/ml CS-1 fibronectin in the presence of medium, anti-CS-1 fibronectin or control

antibodies (W6/32, anti-MHC). (B, C) Adhesion of endothelial cells to plastic plates coated with 5 μg/ml CS-1 fibronectin, in the presence of medium, anti-α4β1 (HP1/2) or control antibodies (P1F6). (D) Cryosections from bFGF stimulated, saline or antibody-treated CAMs were immunostained to detect blood vessel expression of von Willebrand Factor. (E) Angiogenesis was initiated in FVB/N mice by corneal transplantation of polymerized pellets containing 400 ng/ml of VEGF. Animals (n=5) were treated on day 0 and day 3 with anti-α4β1 (PS/2) or control IgG (cIgG). Fifteen minutes prior to sacrifice on day 5, mice were injected intravenously with endothelial specific lectin, Bandeira simplifolia-FITC and tissues were cryopreserved. Angiogenic response to VEGF was quantified as the percent green fluorescent area visible under high power magnification (100X). (F-G) Angiogenesis was initiated in nude mice by subcutaneous injection of 400 μl growth factor reduced matrigel supplemented with 400 ng/ml of bFGF containing (F) 200 μg function blocking rat anti-integrin α4β1 (PS/2) or isotype-matched control antibodies (rat anti-integrin β2) and (G) 50 μM EILDV or EILEV peptides. Fifteen minutes prior to sacrifice on day 5, mice were injected intravenously with endothelial specific lectin, Bandeira simplifolia-FITC. Matrigel plugs were homogenized in RIPA buffer and fluorescence intensity determined.

Figure 20 shows (A) Cytofluorescence analysis of ECs, EPCs, and fibroblasts for UEA-1 lectin binding and uptake of DiI-acetylated LDL. (B) Adhesion of purified EPCs to plastic plates coated with 5 μg/ml fibronectin, CS-1 fibronectin, vitronectin and collagen. (C) Migration of purified EPCs on 8 μm pore transwells coated with 5 μg/ml fibronectin, CS-1 fibronectin, vitronectin and collagen. (D,E) Adhesion of purified EPCs on plastic plates coated with 5 μg/ml vitronectin in the presence of medium, anti-α4β1 (HP1/2), anti-αvβ3 (LM609), anti-αvβ5 (P1F6), or anti-α5β1 (P1F6).

Figure 21 shows that bone marrow derived cells can differentiate into endothelial cells (Ecs).

Figure 22 shows that integrin α4β1 is an early marker of endothelial progenitor cells (EPCs).

Figure 23 shows that endothelial progenitor cells remain integrin α4β1-positive and acquire αv integrin expression.

Figure 24 shows endothelial progenitor cell maturation on days 4, 7, and 9.

Figure 25 shows that integrin α4β1 mediates endothelial progenitor cell adhesion to fibronectin.

Figure 26 shows that integrin α4β1 mediates endothelial progenitor cell adhesion to rsVCAM.

Figure 27 shows that endothelial progenitor cells adhere to endothelial monolayers via integrin α4β1.

Figure 28 shows that endothelial progenitor cells adhere to endothelial monolayers

in a VCAM-dependent manner.

Figure 29 shows the exemplary Tie2BMT model of hematopoietic stem cell role in neovascularization.

Figure 30 shows that antagonists of integrin α4β1 block endothelial progenitor cell entry into neovascular beds.

Figure 31 shows that integrin α4β1 promotes endothelial progenitor cell contributions to angiogenesis *in vivo*.

Figure 32 shows that integrin α4β1 promotes endothelial progenitor cell extravasation and participation in vessel formation.

Figure 33 shows that human CD34+ stem cells home to peripheral tumor vasculature (a) CMTMR labeled stem cells were injected into nude mice with breast carcinomas under dorsal skinfold transparent chambers. (b) *Upper*, Tumor and vasculature in transparent chambers. *Lower*, Peripheral and central tumor vessels are clearly visible. (C) Fluorescence video microscopy of peripheral and central tumor vascular beds. Arrowheads indicate hematopoietic stem cells (200X magnification). (d) Average number of hematopoietic stem cells per 200X microscopic field +/-SEM from (C). (e) Cryosections of tumors immunostained with anti-murine CD31 (green) at 200X and 400X magnification. Hematopoietic stem cells (arrowheads) are in or near blood vessels (arrows). Asterisks indicate P<0.05. Bar=50μm.

Figure 34 shows that integrin α4β1 on human CD34+ stem cells (a) FACs profiles for CD34, CD133 and integrin α4β1 on stem cells. (b) Stem cell adhesion to CS-1 fibronectin in the presence of culture medium, anti-α4β1 (HP2/1) or control antibodies (P1F6) +/-SEM. (c) FACS profiles for VCAM (black) and nonspecific IgG control (grey) on ECs. (d) Stem cells adhesion to HUVECs in the presence of medium, anti-α4β1 (HP2/1) or control antibodies (P1F6) +/-SEM. (e) *Left*, Brightfield/red fluorescence images of stem cells on ECs. *Right*, red fluorescence images of stem cells on ECs in the presence of anti-α4β1 (HP2/1) or control antibodies (cIgG, P1F6). Asterisks indicate P<0.05.

Figure 35 shows that integrin α4β1 and ligands in hematopoietic stem cell homing (a) Cryosections of murine breast carcinomas or normal tissue (colon, left; heart, right) immunostained for CD31 (red) and VCAM or fibronectin (green). Arrowheads indicate blood vessels. Yellow indicates EC expression of VCAM/fibronectin. (b) Cryosections of breast carcinomas (N202) or Lewis lung carcinomas (LLC) from mice injected with hematopoietic stem cells (red, arrowheads) in the presence of anti-human α4β1_antibody or negative controls (Cntrl) immunostained with anti-murine CD31 (green, arrows). (c-d) Average number of hematopoietic stem cells per 200X microscopic field for ©) N202 and (d) LLC tumors +/-SEM. Asterisks indicate P<0.05. Bar=50μm.

Figure 36 shows that integrin α4β1 promotes hematopoietic stem cell homing from

the bone marrow (a) Cryosections of LLC tumors from mice injected with EGFP+Lin- cells (green, arrowheads) and control antibody (cIgG) or anti-$\alpha4\beta1$ immunostained with anti-CD31 (red, arrows). EGFP+ vessels are yellow. (b) Average number of EGFP cells per 200X microscopic field +/-SEM. (C) Cryosections of bFGF or VEGF saturated Matrigel from mice transplanted with Tie2LacZ bone marrow and treated with anti-$\alpha4\beta1$ or control antibody (cIgG) stained to detect beta-galactosidase (200X). (d) Average numbers of LacZ+ cells per 200X field +/-SEM from (C): VEGF (black bars). FGF (white bars). (e) Cryosections from (d) immunostained for beta-galactosidase (green) and CD31 (red). LacZ+/CD31+ vessels are yellow (arrows). (f) Average number of LacZ+/CD31+ vessels per 200X field +/-SEM. Asterisks indicate $P<0.05$. Bar=50μm.

DEFINITIONS

To facilitate understanding of the invention, a number of terms are defined below.

As used in this specification and the appended claims, the singular forms "a," "an" and "the" includes both singular and plural references unless the content clearly dictates otherwise.

As used herein, the term "or" when used in the expression "A or B," where A and B refer to a composition, disease, product, *etc.*, means one, or the other, or both.

The term "on" when in reference to the location of a first article with respect to a second article means that the first article is on top and/or into the second article, including, for example, where the first article permeates into the second article after initially being placed on it.

As used herein, the term "comprising" when placed before the recitation of steps in a method means that the method encompasses one or more steps that are additional to those expressly recited, and that the additional one or more steps may be performed before, between, and/or after the recited steps. For example, a method comprising steps a, b, and c encompasses a method of steps a, b, x, and c, a method of steps a, b, c, and x, as well as a method of steps x, a, b, and c. Furthermore, the term "comprising" when placed before the recitation of steps in a method does not (although it may) require sequential performance of the listed steps, unless the content clearly dictates otherwise. For example, a method comprising steps a, b, and c encompasses, for example, a method of performing steps in the order of steps a, c, and b, the order of steps c, b, and a, and the order of steps c, a, and b, *etc.*

Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as molecular weight, reaction conditions, and so forth as used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters in the specification and claims are approximations that may vary depending upon the desired

properties sought to be obtained by the present invention. At the very least, and without limiting the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Notwithstanding that the numerical ranges and parameters describing the broad scope of the invention are approximation, the numerical values in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains standard deviations that necessarily result from the errors found in the numerical value's testing measurements.

The term "not" when preceding, and made in reference to, any particularly named molecule (such as a protein, nucleotide sequence, *etc.*) or phenomenon (such as cell adhesion, cell migration, cell differentiation, angiogenesis, biological activity, biochemical activity, *etc.*) means that only the particularly named molecule or phenomenon is excluded.

The term "altering" and grammatical equivalents as used herein in reference to the level of any molecule (such as a protein, nucleotide sequence, *etc.*) or phenomenon (such as cell adhesion, cell migration, cell differentiation, angiogenesis, biological activity, biochemical activity, *etc.*) refers to an increase and/or decrease in the quantity of the substance and/or phenomenon, regardless of whether the quantity is determined objectively and/or subjectively.

The term "increase," "elevate," "raise," and grammatical equivalents when in reference to the level of a molecule (such as a protein, nucleotide sequence, *etc.*) or phenomenon (such as cell adhesion, cell migration, cell differentiation, angiogenesis, biological activity, biochemical activity, *etc.*) in a first sample relative to a second sample, mean that the quantity of the substance and/or phenomenon in the first sample is higher than in the second sample by any amount that is statistically significant using any art-accepted statistical method of analysis such as the Student's t-test. In one embodiment, the increase may be determined subjectively, for example when a patient refers to their subjective perception of disease symptoms, such as pain, clarity of vision, *etc*. In another embodiment, the quantity of the substance and/or phenomenon in the first sample is at least 10% greater than, preferably at least 25% greater than, more preferably at least 50% greater than, yet more preferably at least 75% greater than, and most preferably at least 90% greater than the quantity of the same substance and/or phenomenon in a second sample.

The terms "reduce," "inhibit," "diminish," "suppress," "decrease," and grammatical equivalents when in reference to the level of a molecule (such as a protein, nucleotide sequence, *etc.*) or phenomenon (such as cell adhesion, cell migration, cell differentiation, angiogenesis, biological activity, biochemical activity, *etc.*) in a first sample relative to a second sample, mean that the quantity of substance and/or phenomenon in the first sample is lower than in the second sample by any amount that is statistically significant using any

art-accepted statistical method of analysis. In one embodiment, the reduction may be determined subjectively, for example when a patient refers to their subjective perception of disease symptoms, such as pain, clarity of vision, *etc.* In another embodiment, the quantity of substance and/or phenomenon in the first sample is at least 10% lower than, preferably, at least 25% lower than, more preferably at least 50% lower than, yet more preferably at least 75% lower than, and most preferably at least 90% lower than the quantity of the same substance and/or phenomenon in a second sample. A reduced level of a molecule and/or phenomenon need not, although it may, mean an absolute absence of the molecule and/or phenomenon.

Reference herein to any specifically named protein (such as "integrin $\alpha4\beta1$," "vascular cell adhesion molecule, fibronectin, *etc.*) refers to a polypeptide having at least one of the biological activities (such as those disclosed herein and/or known in the art) of the specifically named protein, wherein the biological activity is detectably by any method. In a preferred embodiment, the amino acid sequence of the polypeptide has at least 95% homology (*i.e.*, identity) with the amino acid sequence of the specifically named protein. Reference herein to any specifically named protein (such as "integrin $\alpha4\beta1$," "vascular cell adhesion molecule, fibronectin, *etc.*) also includes within its scope fragments, fusion proteins, and variants of the specifically named protein that have at least 95% homology with the amino acid sequence of the specifically named protein.

The term "fragment" when in reference to a protein refers to a portion of that protein that may range in size from four (4) contiguous amino acid residues to the entire amino acid sequence minus one amino acid residue. Thus, a polypeptide sequence comprising "at least a portion of an amino acid sequence" comprises from four (4) contiguous amino acid residues of the amino acid sequence to the entire amino acid sequence.

The term"variant" of a protein as used herein is defined as an amino acid sequence which differs by insertion, deletion, and/or conservative substitution of one or more amino acids from the protein. The term "conservative substitution" of an amino acid refers to the replacement of that amino acid with another amino acid which has a similar hydrophobicity, polarity, and/or structure. For example, the following aliphatic amino acids with neutral side chains may be conservatively substituted one for the other: glycine, alanine, valine, leucine, isoleucine, serine, and threonine. Aromatic amino acids with neutral side chains which may be conservatively substituted one for the other include phenylalanine, tyrosine, and tryptophan. Cysteine and methionine are sulphur-containing amino acids which may be conservatively substituted one for the other. Also, asparagine may be conservatively substituted for glutamine, and *vice versa*, since both amino acids are amides of dicarboxylic amino acids. In addition, aspartic acid (aspartate) my be conservatively substituted for glutamic acid (glutamate) as both are acidic, charged (hydrophilic) amino acids. Also,

lysine, arginine, and histidine my be conservatively substituted one for the other since each is a basic, charged (hydrophilic) amino acid. Guidance in determining which and how many amino acid residues may be substituted, inserted or deleted without abolishing biological and/or immunological activity may be found using computer programs well known in the art, for example, DNAStar^{TM} software. In one embodiment, the sequence of the variant has at least 95% identity, preferably at least 90% identity, more preferably at least 85% identity, yet more preferably at least 75% identity, even more preferably at least 70% identity, and also more preferably at least 65% identity with the sequence of the protein in issue.

Reference herein to any specifically named nucleotide sequence (such as a sequence encoding integrin $\alpha 4\beta 1$, *etc.*) includes within its scope fragments, homologs, and sequences that hybridize under high and/or medium stringnet conditions to the specifically named nucleotide sequence, and that have at least one of the biological activities (such as those disclosed herein and/or known in the art) of the specifically named nucleotide sequence, wherein the biological activity is detectable by any method.

The nucleotide "fragment" may range in size from an exemplary 10, 20, 50, 100 contiguous nucleotide residues to the entire nucleic acid sequence minus one nucleic acid residue. Thus, a nucleic acid sequence comprising "at least a portion of" a nucleotide sequence comprises from ten (10) contiguous nucleotide residues of the nucleotide sequence to the entire nucleotide sequence.

The term "homolog" of a specifically named nucleotide sequence refers to an oligonucleotide sequence which has at least 95% identity, more preferably at least 90% identity, yet more preferably at least 85% identity, yet more preferably at least 80% identity, also more preferably at least 75% identity, yet more preferably at least 70% identity, and most preferably at least 65% identity with the sequence of the nucleotide sequence in issue.

With respect to sequences that hybridize under stringent condition to the specifically named nucleotide sequence, high stringency conditions comprise conditions equivalent to binding or hybridization at 68°C in a solution containing 5X SSPE, 1% SDS, 5X Denhardt's reagent and 100 µg/ml denatured salmon sperm DNA followed by washing in a solution containing 0.1X SSPE, and 0.1% SDS at 68°C when a probe of about 100 to about 1000 nucleotides in length is employed. "Medium stringency conditions" when used in reference to nucleic acid hybridization comprise conditions equivalent to binding or hybridization at 42°C in a solution of 5X SSPE (43.8 g/l NaCl, 6.9 g/l NaH2PO4-H2O and 1.85 g/l EDTA, pH adjusted to 7.4 with NaOH), 0.5% SDS, 5X Denhardt's reagent and 100 µg/ml denatured salmon sperm DNA followed by washing in a solution comprising 1.0X SSPE, 1.0% SDS at 42°C when a probe of about 500 nucleotides in length is employed.

The term "equivalent" when made in reference to a hybridization condition as it relates to a hybridization condition of interest means that the hybridization condition and the

hybridization condition of interest result in hybridization of nucleic acid sequences which have the same range of percent (%) homology. For example, if a hybridization condition of interest results in hybridization of a first nucleic acid sequence with other nucleic acid sequences that have from 85% to 95% homology to the first nucleic acid sequence, then another hybridization condition is said to be equivalent to the hybridization condition of interest if this other hybridization condition also results in hybridization of the first nucleic acid sequence with the other nucleic acid sequences that have from 85% to 95% homology to the first nucleic acid sequence.

As will be understood by those of skill in the art, it may be advantageous to produce a nucleotide sequence encoding a protein of interest, wherein the nucleotide sequence possesses non-naturally occurring codons. Therefore, in some preferred embodiments, codons preferred by a particular prokaryotic or eukaryotic host (Murray et al., Nucl. Acids Res., 17 (1989)) are selected, for example, to increase the rate of expression or to produce recombinant RNA transcripts having desirable properties, such as a longer half-life, than transcripts produced from naturally occurring sequence.

The term "naturally occurring" as used herein when applied to an object (such as cell, *etc.*) and/or chemical (such as amino acid, amino acid sequence, nucleic acid, nucleic acid sequence, codon, *etc.*) means that the object and/or compound can be found in nature. For example, a naturally occurring polypeptide sequence refers to a polypeptide sequence that is present in an organism (including viruses) that can be isolated from a source in nature, wherein the polypeptide sequence has not been intentionally modified by man in the laboratory.

The terms nucleotide sequence "comprising a particular nucleic acid sequence" and protein "comprising a particular amino acid sequence" and equivalents of these terms, refer to any nucleotide sequence of interest and to any protein of interest that contains the particularly named nucleic acid sequence and the particularly named amino acid sequence, respectively. The invention does not limit on the source (*e.g.*, cell type, tissue, animal, *etc.*), nature (*e.g.*, synthetic, recombinant, purified from cell extract, *etc.*), and/or sequence of the nucleotide sequence of interest and/or protein of interest. In one embodiment, the nucleotide sequence of interest and protein of interest include coding sequences of structural genes (*e.g.*, probe genes, reporter genes, selection marker genes, oncogenes, drug resistance genes, growth factors, *etc.*).

The term "chosen from A, B and C" means selecting one or more of A, B, and C.

A "composition comprising a particular polynucleotide sequence" as used herein refers broadly to any composition containing the recited polynucleotide sequence. The composition may comprise an aqueous solution containing, for example, salts (*e.g.*, NaCl), detergents (*e.g.*, SDS), and other components (*e.g.*, Denhardt's solution, dry milk, salmon

sperm DNA, *etc.*).

The terms "hematopoietic progenitor cell" and "HPC" refer to an uncommitted (*i.e.*, undifferentiated) and/or partially committed (*i.e.*, partially differentiated) cell. Hematopoietic progenitor cells are oligopotent, that is, they have the ability to differentiate into more than one cell type, comprising, without limitation, granulocytes (*e.g.*, promyelocytes, neutrophils, eosinophils, basophils), erythrocytes (*e.g.*, reticulocytes, erythrocytes), thrombocyte (*e.g.*, megakaryoblasts, platelet producing megakaryocytes, platelets), and monocytes (*e.g.*, monocytes, macrophages).

Hematopoietic progenitor cells usually, but not necessarily, reside in the bone marrow. They are also found in the blood circulation and are also resident within other tissues. Hematopoietic progenitor cells are identified by surface markers. For example, human progenitor cells are identified by the surface marker CD34 (CD34+ cells). 0.1% of circulating cells in the blood are CD34+ while 2.1% of bone marrow cells are CD34+. Hematopoietic stem cells resident in tissues have also been found to be CD34+. Bone marrow derived (*i.e.*, isolated from bone marrow or from the circulation) and tissue derived CD34+ cells can differentiate into muscle, neuronal tissues, epithelial tissues, vascular cells, immune cells and others and may be used to repopulate target tissues. Hematopoietic progenitor cells have been used therapeutically to repopulate damaged and disease tissues and spontaneously participate in tissues repair processes and pathologies in vivo (Belicci et. al. (2004) J. Neurosci Res. 77, 475-86; Otani et al., 2002, Nature Med. 8, 1004-1010; Otani et. al., (2004) J. Clin. Invest. 114, 765-774; Tamaki et. al. (2002) J. Cell Biol. 157, 571-577; Torrente et al. (2004) J. Clin. Invest. 114, 182-195; Hashimoto et. al. (2004) J. Clin. Invest. 113, 243-252)

The term "hematopoietic progenitor cell" expressly includes hematopoietic stem cells, endothelial progenitor cells, lymphendothelial progenitor cells, mesenchymal precursor cells, myeloid progenitor cells, lymphoid progenitor cells, granulocyte progenitor cell, macrophage progenitor cells, megakaryocyte progenitor cells, erythroid progenitor cells, Pro-B cells and Pro T cells (Terskikh (2003) Blood 102, 94-101).

Hematopoietic progenitor cells may be isolated and cultured using methods disclosed herein as well as those known in the art, such as from blood products (*e.g.*, U.S. Pat. Nos. 5,061,620 and 6,645,489 incorporated by reference). A "blood product" as used in the present invention defines a product obtained from the body or an organ of the body containing cells of hematopoietic origin. Such sources include unfractionated bone marrow, umbilical cord, peripheral blood, liver, thymus, lymph and spleen. It will be apparent to those of ordinary skill in the art that all of the aforementioned crude or unfractionated blood products can be enriched for cells having "hematopoietic progenitor cell" characteristics in a number of ways. For example, the blood product can be depleted from the more

differentiated progeny. The more mature, differentiated cells can be selected against, via cell surface molecules they express. Additionally, the blood product can be fractionated selecting for CD34.sup.+ cells. Such selection can be accomplished using methods disclosed herein, as well as commercially available magnetic anti-CD34 beads (Dynal, Lake Success, N.Y.). Unfractionated blood products can be obtained directly from a donor or retrieved from cryopreservative storage.

The terms "hematopoietic stem cell" and "HSC" refer to an oligopotent cell type that gives rise to more differentiated "precursor cells" such as, without limitation, endothelial progenitor cells, lymphendothelial progenitor cells, mesenchymal precursor cells, myeloid progenitor cells, lymphoid progenitor cells, granulocyte progenitor cell, macrophage progenitor cells, megakaryocyte progenitor cells, erythroid progenitor cells, Pro-B cells and Pro T cells (Terskikh et. al. (2003) supra). HSCs reside in the bone marrow, often attached to bone, but are also found in the circulation and also resident within other tissues. Hematopoietic stem cells have the capacity for self-renewal while more committee progenitors do not (Terskikh et. al. (2003) supra). HSCs and HPCs share common cell surface markers, in particular, for human cells by the marker CD34. HSCs are Lineage negative (lacking specific markers for any differentiated cells, such as B220 on B cells, CD3 on T-cells, CD11b on myeloid cells, *etc.*), CD34+, c-kit+ (Belicci et. al. (2004) supra). In mice these cells are c-kit+, Thyl.1lo, Sca-1+ and Lin- (Rafii et al. 2003, supra). Additionally, some progenitors, including endothelial progenitors, express CD133.

The terms "endothelial progenitor cells," "EPCs," "endothelial cell progenitors," and "lymphendothelial progenitor cells" refer to cells that arise from HSCs and that give rise to differentiated endothelial and lymphendothelial cells, respectively. EPCs are CD34+, CD133+, c-kit+ and Lin- (Rafii et al. 2003, supra). Furthermore they may be VEGFR2+ and/or VEGFR3+ (Rafii et al. 2003, supra). Human endothelial progenitor cells express the surface molecules CD34, flk-1, and/or tie-2 (Isner *et al.*, U.S. Patent No. 5,980,887, the entire contents of which are herein incorporated by reference). Mouse endothelial cell progenitors express the *TM* gene, *tie-2* gene, and/or *fgf3* gene, and/or stain with the GSL I B4 lectin (Hatzopoulos *et al.* (1998) Development 125:1457-1468).

The term "mesenchymal progenitor cells" refers to cells arising from HSCs and that give rise to fibroblasts and other stromal cells such as bone, adipose tissues and cartilage (Gronthos et. al., 2003. J. Cell Sci. 116, 1827-1835).

The term "myeloid progenitor cells" refers to cells arising from HSCs and that are precursors that give rise to granulocytes, macrophages, erythrocytes, megakaryocytes (and thus platelets) and possibly endothelial cells, muscle cells and other tissues (Terskikh, et. al. (2003) supra).

The term "lymphoid progenitor cells" refers to cells arising from HSCs and that give

rise to T and B cells (Otani et. al. (2002) supra).

As used herein, the term "tissue exhibiting angiogenesis" refers to a tissue in which new blood vessels are developing from pre-existing blood vessels.

As used herein, the term "inhibiting angiogenesis," "diminishing angiogenesis," "reducing angiogenesis," and grammatical equivalents thereof refer to reducing the level of angiogenesis in a tissue to a quantity which is preferably 10% less than, more preferably 50% less than, yet more preferably 75% than, even more preferably 90% less than, the quantity in a control tissue, and most preferably is at the same level which is observed in a control tissue. A reduced level of angiogenesis need not, although it may, mean an absolute absence of angiogenesis. The invention does not require, and is not limited to, methods that wholly eliminate angiogenesis.

The level of angiogenesis may be determined using methods well known in the art, including, without limitation, counting the number of blood vessels and/or the number of blood vessel branch points, as discussed herein. An alternative assay involves an *in vitro* cell adhesion assay that shows whether a compound inhibits the ability of $\alpha4\beta1$-expressing cells (*e.g.* M21 melanoma cells) to adhere to VCAM or fibronectin. Another *in vitro* assay contemplated includes the tubular cord formation assay that shows growth of new blood vessels at the cellular level (D. S. Grant *et al.*, Cell, 58: 933-943 (1989)). Art-accepted *in vivo* assays are also known, and involve the use of various test animals such as chickens, rats, mice, rabbits and the like. These *in vivo* assays include the chicken chorioallantoic membrane (CAM) assay, which is suitable for showing anti-angiogenic activity in both normal and neoplastic tissues (D. H. Ausprunk, Amer. J. Path., 79, No. 3: 597-610 (1975) and L. Ossonowski and E. Reich, Cancer Res., 30: 2300-2309 (1980)). Other *in vivo* assays include the mouse metastasis assay, which shows the ability of a compound to reduce the rate of growth of transplanted tumors in certain mice, or to inhibit the formation of tumors or pre-neoplastic cells in mice which are predisposed to cancer or which express chemically-induced cancer (M. J. Humphries *et al.*, Science, 233: 467-470 (1986) and M. J. Humphries *et al.*, J. Clin. Invest., 81: 782-790 (1988)).

The term "integrin $\alpha4\beta1$" is interchangeably used with the terms "CD49d/CD29," "very late antigen 4," and "VLA4" to refer to a member of the family of integrins. An "integrin" is an extracellular receptor that is expressed in a wide variety of cells and binds to specific ligands in the extracellular matrix. The specific ligands bound by integrins can contain an arginine-glycine-aspartic acid tripeptide (Arg-Gly-Asp; RGD) or a leucine-aspartic acid-valine (Leu-Asp-Val) tripeptide, and include, for example, fibronectin, vitronectin, osteopontin, tenascin, and von Willebrands's factor. Integrin $\alpha4\beta1$ is a heterodimeric cell surface adhesion receptor composed of an $\alpha4$ and $\beta1$subunits that bind to ligands which are present in the extracellular matrix (ECM) as well as on the cell surface. An exemplary $\alpha4$

polypeptide sequence is shown in Figure 1, and an exemplary β1 polypeptide sequence is shown in Figure 2.

The term "integrin α4β1" is contemplated also to include a portion of α4β1. The term "portion," when used in reference to a protein (as in a "portion of α4β1") refers to a fragment of that protein. The fragments may range in size from three (3) contiguous amino acid residues to the entire amino acid sequence minus one amino acid residue. Thus, a polypeptide sequence comprising "at least a portion of an amino acid sequence" comprises from three (3) contiguous amino acid residues of the amino acid sequence to the entire amino acid sequence.

In one preferred embodiment, the portion of integrin α4β1 comprises a portion of the α4 polypeptide sequence. In a more preferred embodiment, the portion of the α4 polypeptide sequence shown in Figure 1 comprises the sequence IVTCGHRWKNIFYIKNENKLPTGGCYGVPPDLRTELSKRIAPCYQDYVKKFGENFAS CQAGISSFYTKDLIVMGAPGSSYWTGSLFVYNITTNKYKAFLDKQNQVKFGSYLGY SVGAGHFRSQHTTEVVGGAPQHEQIGKAYIFSIDEKELNILHEMKGKK (SEQ ID NO:10) (from amino acid 141 to amino acid 301). In a more preferred embodiment, the portion of integrin α4β1 comprises the sequence GHRWKN IFYIKNENKLPTGG (SEQ ID NO:11) (from amino acid 145 to amino acid 164), the sequence YQDYVKKFGENFAS (SEQ ID NO:12) (from amino acid 184 to amino acid 197), the sequence SYWTGS (SEQ ID NO:13) (from amino acid 219 to amino acid 224), the sequence GGAPQHEQIGK (SEQ ID NO:14) (from amino acid 270 to amino acid 280), and the sequence YNVDTES ALLYQGPHNT IFGYSVVLHS HGANRWLLVG APTANWLANA SVINP (SEQ ID NO:54) (from amino acid 34 to amino acid 85). In an alternative embodiment, the invention expressly includes portions of the α4 polypeptide sequence (which is exemplified by the sequence of Figure 1) that contain the fore-mentioned portions. Such sequences include, for example, GRPYNVDTESALLYQGPHNTLFGYSVVLHSHGANRWLLVG APTANWLANASVINPGAIYR (SEQ ID NO:55), GVPTGRPYNVDTESAL LYQGPHNT LFGYSVVLHSHGANRWLLVGAPTANWLANASVI NPGAIYRCRIGKNPGQT (SEQ ID NO:56), IVTCGHRWKNIFYIKNENKLPTGGCYG (SEQ ID NO:57), GHRWKNIFYIKNENKLPTGGCYGVPPDLRTELSK (SEQ ID NO:58), APCYQDYVKKFGENFAS (SEQ ID NO:59), CYQDYVKKFGENFASCQA GISSFYTKDL (SEQ ID NO:60), GSSYWTGSLFVYNI (SEQ ID NO:61), RSQHTTEVVGGAPQHEQIGK (SEQ ID NO:62), GGAPQHEQIGKAYIFSIDEKEL (SEQ ID NO:63), and/or GGAPQHEQIGKA (SEQ ID NO:64).

The terms "isolated," "purified," and grammatical equivalents thereof when used in reference to a molecule (*e.g.*, protein, DNA, RNA, *etc.*) or article (*e.g.*, hematopoietic progenitor cell) in a sample refer to the reduction (by at least 10%, preferably by at least

25%, more preferably by at least 50%, even more preferably by at least 75%, and most preferably by at least 90%) in the amount of at least one contaminant molecule and/or article from the sample. Thus, purification results in an "enrichment," *i.e.*, an increase, in the amount of the desirable molecule and/or article relative to one or more other molecules and/or articles in the sample.

A "non-endothelial cell" is any cell type other than an endothelial cell (*i.e.*, is not an endothelial cell) such as, without limitation, stem cell, lymph cell, mesenchymal cell, myeloid cell, lymphoid cell, granulocyte cell, macrophage cell, megakaryocyte cell, erythroid cell, B cell, T cell, bone marrow cell, muscle cell, neural cell, *etc.*

The terms "disease" and "pathological condition" are used interchangeably to refer to a state, signs, and/or symptoms that are associated with any impairment, interruption, cessation, or disorder of the normal state of a living animal or of any of its organs or tissues that interrupts or modifies the performance of normal functions, and may be a response to environmental factors (such as malnutrition, industrial hazards, or climate), to specific infective agents (such as worms, bacteria, or viruses), to inherent defect of the organism (such as various genetic anomalies, or to combinations of these and other factors. The term "disease" includes responses to injuries, especially if such responses are excessive, produce symptoms that excessively interfere with normal activities of an individual, and/or the tissue does not heal normally (where excessive is characterized as the degree of interference, or the length of the interference).

DESCRIPTION OF THE INVENTION

The present invention satisfies the need in the art by providing methods for altering hematopoietic progenitor cell adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell type. The invention also provides methods for screening test compounds for altering the level of hematopoietic cell adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell type. The invention further provides methods for isolating hematopoietic progenitor cells. The methods of the invention are useful in, for example, diagnosis, prophylaxis, and reduction of symptoms of diseases and conditions that are associated with HPC adhesion, migration and differentiation. The methods of the present invention are also useful in isolating HPCs cells, and in determining the mechanisms that underlie development and wound healing. The methods of the invention are based, in part, on the inventor's fortuitous discovery that integrin $\alpha4\beta1$ plays a role in HPC adhesion, migration, and differentiation.

Hematopoietic stem cells provide up to 15% of new vessels in tumors by differentiating into endothelial cells (ECs) (Ruzinova et al. Cancer Cell 4:277-289 (2003)),

but some hematopoietic stem cells may also promote angiogenesis by differentiating into cells such as monocytes, which secrete angiogenic factors (Cursiefen et al. (2004) J. Clin. Invest. 113:1040-1050). As most CD34+ cells express integrin α4β1 and α4β1 antagonists nearly completely blocked hematopoietic stem cell homing, data herein (Examples 17-24) indicate that α4β1 regulates both roles for hematopoietic stem cells in neovascularization. It is also not clear whether hematopoietic stem cells, partially committed precursors cells or a combination of the two participate in angiogenesis. Our data shows that endothelial progenitor cells also home to tumors in an α4β1 dependent manner. Data herein thus show that inhibition of α4β1 blocks the homing of the exemplary hematopoietic stem cells to the neovasculature and subsequent outgrowth into endothelium.

It is the inventor's consideration that the exemplary circulating hematopoietic stem cells home to sites of neovascularization (Asahara et al. (1997) supra; Rafii et al. (2003) Nat. Med. 9, 702-12; Takahashi et al. (1999) Nat. Med. 5,434-438; Kawamoto et al. (2001) Circulation 103, 634-637; Hattori et al. (2001) J. Exp. Med. 193, 1005-1014; Lyden et al. (2001) Nat. Med. 7, 1194-201; Ruzinova et al. (2003) Cancer Cell. 4: 277-289; Jain et al. (2003) Cancer Cell 3, 515-516; Religa et al. (2002) Transplantation 74, 1310-1315; and Boehm et al. (2004) J. Clin. Invest. 114, 419-426)), where they give rise to approximately 15% of the vasculature (Ruzinova et al. (2003) Cancer Cell. 4: 277–289). They also home to muscle, brain and other tissues, where they participate in tissue regeneration or pathogenesis by differentiating into muscle, nerve and other cell types (Priller (2001) et al. J. Cell Biol. 155, 733-738; LaBarge et al. (2002) Cell. 111, 589-601; Torrente et al. (2003) J. Cell Biol. 162, 511-520; 13. Religa et al. (2002) Transplantation 74, 1310-1315; and Boehm et al. (2004) J. Clin. Invest. 114, 419-426)).

Integrin α4β1-VCAM interactions promote heterotypic cell adhesion during many processes *in vivo*. α4β1-VCAM interactions are involved in normal embryonic development, as embryonic loss of either molecule inhibits fusion of the chorion with the allantois (Yang et al. (1995) Development 121, 549-560; and Kwee et al. (1995) Development 121, 489-503) and of endocardium with myocardium (Yang et al. (1995) Development 121, 549-560; and Kwee et al. (1995) Development 121, 489-503). Integrin α4β1 interactions with fibronectin and/or VCAM are also involved in immune cell trafficking in inflammation (Guan et al. (2990) Cell 60, 53-61; and Elices et al. (1990) Cell 60, 577-584) and cancer (Melder et al. (1996) Nat Med. 2:992-997), for adhesion of immune cell precursors to bone marrow EC and for the homing of these cells back to the bone marrow (Simmons et al. (1992) Blood. 80, 388-395; Papayannopoulou et al. (2001) Blood 98, 2403-2411; Craddock et al. (1997) Blood 90, 4779-4788; and Miyake et al. (1991) J. Cell Biol.114, 557-565). In one embodiment, our data demonstrate a novel function of the interaction of α4β1 with the exemplary ligands VCAM and fibronectin, that

is, to promote the association of the exemplary hematopoietic stem cells with endothelial cells during neovascularization and tissue remodeling.

Data herein (*e.g.*, Examples 17-24, Figures 21-36) show that integrin α4β1 plays a central role in the homing of the exemplary hematopoietic stem cells to tumors, inflammatory tissues and injured tissue, and that manipulation of the expression and/or function of integrin α4β1 and its ligands offers a means for modulating pathological processes that involve hematopoietic progenitor cells, such as hematopoietic stem cells.

The invention is further discussed below under the headings: A) Integrin α4β1 Ligands, B) Agents Which Alter Binding Of Integrin α4β1 To Its Ligands, C) Integrin α4β1 Mediates Trafficking of Endothelial Progenitor Cells, As Exemplified By Endothelial Stem Cells, During Neovascularization, D) Altering Hematopoietic Progenitor Cell Adhesion, Migration and Differentiation, E) Altering Hematopoietic Progenitor Cell Adhesion, Migration, and Differentiation, F) Detecting Hematopoietic Progenitor Cells That Express Integrin α4β1, G) Screening Compounds, and H) Isolating Hematopoietic Progenitor Cells.

A. Integrin α4β1 Ligands

The methods of the invention employ agents which inhibit the specific binding of integrin α4β1 with one or more of its ligands. The term "ligand" as used herein in reference to a ligand for the integrin α4β1 receptor, refers to a molecule and/or portion thereof, to which α4β1 specifically binds. In one embodiment, binding of the ligand initiates a specific biological response (*e.g.*, hematopoietic progenitor cell adhesion, migration, and/or differentiation) and/or the transduction of a signal in a cell. Integrin α4β1 ligands may be present on the cell surface or present in the extracellular matrix (ECM).

In one preferred embodiment, an integrin α4β1 ligand that is present on the cell surface is exemplified by the vascular cell adhesion molecule (VCAM). An example of the polypeptide sequence of VCAM is shown in Figure 3. In another preferred embodiment, the integrin α4β1 ligand is a portion of VCAM. Preferred portions of VCAM (Figure 3A, GenBank Accession Nos. P19320) comprise the amino acid sequence RTQIDSPLNG (SEQ ID NO:15) (from amino acid 60 to amino acid 69); the amino acid sequence RTQIDSPLSG (SEQ ID NO:16) (from amino acid 348 to amino acid 357); and the amino acid sequence KLEK (SEQ ID NO:17) (from amino acid 103 to amino acid 106, and from amino acid 391 to amino acid 394). Other portions of VCAM are also contemplated, which preferably contain one of more of the RTQIDSPLNG (SEQ ID NO:15), RTQIDSPLSG (SEQ ID NO:16), or KLEK (SEQ ID NO:17) sequences. These are exemplified by, but not limited to, WRTQIDSPLNGK (SEQ ID NO:65), SWRTQIDSPLNGKV (SEQ ID NO:66), SWRTQIDSPLNGKVT (SEQ ID NO:67), PFFSWRTQIDSPLNGKVTNE (SEQ ID NO:68), SRKLEKGI (SEQ ID NO:69), CESRKLEKGIQV (SEQ ID NO:70),

ATCESRKLEKGIQVEI (SEQ ID NO:71), LCTATCESRKLEKGIQVEIYSFPKDPE (SEQ ID NO:72), GHKKLEKGIQVEL (SEQ ID NO:73), VTCGHKKLEKGI (SEQ ID NO:74), TCGHKKLEKGIQVELYSFPRDPE (SEQ ID NO:75), PVSFENEHSYLCTVTCGHKKLEKG (SEQ ID NO:76), RTQIDSPLSGK (SEQ ID NO:77), FSWRTQIDSPLSGKVR (SEQ ID NO:78), and/or ESPSFWWRTQIDSPLSGK (SEQ ID NO:79).

In another preferred embodiment, an integrin α4β1 ligand that is present in the ECM is exemplified by fibronectin. An exemplary polypeptide sequence of fibronectin is shown in Figure 4. In another preferred embodiment, the integrin α4β1 ligand is a portion of fibronectin. Preferred portions of fibronectin as exemplified in Figure 4 include the IIICS sequence (SEPLIGRKKTDELPQLVTLPHPNLHGPE ILDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHGFRRTTPPTTAT PIRHRPRPYPPNVGEEIQIGHIPREDVDYHLYPHGPGLNPNAST) (SEQ ID NO:18) from amino acid 1982 to amino acid 2111, which encodes two α4β1 binding sites. In one more preferred embodiment, the portion comprises the CS-1 sequence which contains the amino acid sequence LDV (SEQ ID NO:19) (from amino acid 2011 to amino acid 2013). In an alternative embodiment, the portion comprises the CS-5 sequence which contains the amino acid sequence REDV (SEQ ID NO:20) (from amino acid 2091 to amino acid 2094). In yet another preferred embodiment, the portion comprises the amino acid sequence IDAPS (SEQ ID NO:21) (from amino acid 1903 to amino acid 1907). The invention further includes portions of fibronectin that contain the fore-mentioned sequences, as exemplified by, but not limited to, the sequences TAIDAPSNLRDAS (SEQ ID NO:80), TAIDAPSNLRFLATTP (SEQ ID NO:81), RSSPVVIDASTAIDAPS (SEQ ID NO:82), IDAPSNLRFLATTPNSLLV (SEQ ID NO:83), IDAPSNLRFLATTPNSLLVSWQPPRARITGYIIKYE (SEQ ID NO:84), IDDVPST (SEQ ID NO:85), NLHGPEILDVPSTVQK (SEQ ID NO:86), PHPNLHGPEILDV (SEQ ID NO:87), ILDVPSTVQKTPFVTHPGYD (SEQ ID NO:88), VTLPHPNLHGPEILDVP (SEQ ID NO:89), EILDV (SEQ ID NO:90), IPREDVDY (SEQ ID NO:91), GHIPRDDVD (SEQ ID NO:92), GHIPREDV (SEQ ID NO:93), LDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHG FRRTTPPTTATPIRHRPRPYPPNVGEEIQIGHIPREDV (SEQ ID NO:94), and/or PEILDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHGFRRTTPPTT TATPIRHRPRPYPPNVGEEIQIGHIPREDVDY (SEQ ID NO:95).

Integrin α4β1 ligands other than VCAM, fibronectin, and portions thereof are also contemplated to be within the scope of the invention. These ligands may be determined using routine methods available to those skilled in the art. For example, the existence of antibodies against VCAM, fibronectin, and integrin α4β1 makes possible methods for

isolating other integrin α4β1 and integrin α4β1 ligands. One method takes advantage of an antibody characteristic known as idiotypy. Each antibody contains a unique region that is specific for an antigen. This region is called the idiotype. Antibodies themselves contain antigenic determinants; the idiotype of an antibody is an antigenic determinant unique to that molecule. By immunizing an organism with antibodies, one can raise "anti-antibodies" that recognize antibodies, including antibodies that recognize the idiotype. Antibodies that recognize the idiotype of another antibody are called anti-idiotypic antibodies. Some anti-idiotypic antibodies mimic the shape of the original antigen that the antibody recognizes and are said to bear the "internal image" of the antigen (Kennedy (1986) Sci. Am. 255:48-56). For example, anti-idiotypic antibodies have been successfully generated against anti-ELAM1 antibodies and were found to recognize the ELAM1 ligand, which (similarly to integrin α4β1) is a molecule expressed on the surface of endothelial cells (U.S. Patent No. 6,252,043, incorporated in its entirety by reference).

When the antigen is a ligand, certain anti-idiotypes can bind to that ligand's receptor. Several of these have been identified, including anti-idiotypes that bind to receptors for insulin, angiotensin II, adenosine I, adrenalin, and rat brain nicotine and opiate receptors (Carlsson and Glad (1989) Bio/Technology 7:567-73).

B. Agents Which Alter Binding Of Integrin α4β1 To Its Ligands

Some preferred methods of the present invention include the step of utilizing an agent that alters (*i.e.*, increases or decreases) the specific binding of α4β1 to one or more of its ligands. The term "specific binding," as used herein in reference to the binding of an agent to either integrin α4β1 or an integrin α4β1 ligand, means that the interaction is dependent upon the presence of a particular structure on integrin α4β1 or its ligand, respectively. For example, if an agent is specific for epitope "A," the presence of a protein containing epitope A (or free, unlabelled A) in a reaction containing labeled "A" and the agent will reduce the amount of labeled A bound to the agent.

The terms "inhibit the specific binding" and "reduce the specific binding" when used in reference to the effect of an agent on the specific binding of integrin α4β1 with an integrin α4β1 ligand, mean that the agent reduces the level of specific binding of integrin α4β1 with its ligand to a quantity which is preferably 10% less than, more preferably 50% less than, yet more preferably 75% less than, even more preferably 90% less than, the quantity of specific binding in a control sample, and most preferably is at the same level which is observed in a control sample, as detected by (for example) an Enzyme Linked Immunosorbant Assay (ELISA). A reduced level of specific binding need not, although it may, mean an absolute absence of specific binding. The invention does not require, and is not limited to, methods that wholly eliminate specific binding of integrin α4β1 with its

ligand.

The term "antagonist" is used herein to mean a molecule, (*e.g.*, antibody) which can inhibit the specific binding of a receptor and its ligand. An anti-α4β1 integrin antibody, which inhibits the specific binding of α4β1 with fibronectin, is an example of an α4β1 antagonist. An antagonist can act as a competitive inhibitor or a noncompetitive inhibitor of α4β1 binding to its ligand.

The terms "agent," "test agent," "test compound," "compound," " "molecule," and "test molecule," refer to any type of molecule (for example, a peptide, nucleic acid, carbohydrate, lipid, organic, and inorganic molecule, *etc.*) obtained from any source (for example, plant, animal, and environmental source, *etc.*), or prepared by any method (for example, purification of naturally occurring molecules, chemical synthesis, genetic engineering methods, *etc.*). Agents comprise both known and potential compounds. Agents are exemplified by, but not limited to, antibodies, nucleic acid sequences such as antisense and ribozyme sequences, and compounds produced by chemical libraries, phage libraries, *etc.* as further described below.

Without intending to limit the invention to any mechanism, and recognizing that an understanding of a mechanism is not required, it is contemplated that an agent can inhibit the specific binding of an integrin α4β1 receptor with its ligand by various mechanisms, including, for example, by binding to the binding site which is located on the ligand (*e.g.*, VCAM) thereby inhibiting the binding of the integrin α4β1 receptor to its binding site on the ligand, or by binding to a site other than the binding site on the ligand and sterically hindering the binding of the integrin α4β1 receptor to the binding site on the ligand. Alternatively, the agent may bind to integrin α4β1 (rather than to the integrin α4β1 ligand) thereby causing a conformational or other change in the receptor that inhibits binding of integrin α4β1 to the ligand.

1. Antibodies

In one embodiment, the agent that inhibits the specific binding of α4β1 to one or more of its ligands is an antibody. The terms "antibody" and "immunoglobulin" are interchangeably used to refer to a glycoprotein or a portion thereof (including single chain antibodies), which is evoked in an animal by an immunogen and which demonstrates specificity to the immunogen, or, more specifically, to one or more epitopes contained in the immunogen. The term "antibody" expressly includes within its scope antigen binding fragments of such antibodies, including, for example, Fab, $F(ab')_2$, Fd or Fv fragments of an antibody. The antibodies of the invention also include chimeric and humanized antibodies. Antibodies may be polyclonal or monoclonal. The term "polyclonal antibody" refers to an immunoglobulin produced from more than a single clone of plasma cells; in contrast

"monoclonal antibody" refers to an immunoglobulin produced from a single clone of plasma cells.

Antibodies contemplated to be within the scope of the invention include naturally occurring antibodies as well as non-naturally occurring antibodies, including, for example, single chain antibodies, chimeric, bifunctional and humanized antibodies, as well as antigen-binding fragments thereof. Naturally occurring antibodies may be generated in any species including murine, rat, rabbit, hamster, human, and simian species using methods known in the art. Non-naturally occurring antibodies can be constructed using solid phase peptide synthesis, can be produced recombinantly or can be obtained, for example, by screening combinatorial libraries consisting of variable heavy chains and variable light chains as previously described (Huse *et al.*, Science 246:1275-1281 (1989)). These and other methods of making, for example, chimeric, humanized, CDR-grafted, single chain, and bifunctional antibodies are well known to those skilled in the art (Winter and Harris, Immunol. Today 14:243-246 (1993); Ward *et al.*, Nature 341:544-546 (1989); Hilyard *et al.*, Protein Engineering: A practical approach (IRL Press 1992); and Borrabeck, Antibody Engineering, 2d ed. (Oxford University Press 1995).

As used herein, the term "antibody" when used in reference to an anti-integrin antibody, particularly an anti-integrin $\alpha 4\beta 1$ antibody, refers to an antibody which specifically binds to one or more epitopes on an integrin $\alpha 4\beta 1$ polypeptide or peptide portion thereof, and which may or may not include some or all of an RGD binding domain. In one embodiment, an anti-integrin $\alpha 4\beta 1$ antibody, or antigen binding fragment thereof, is characterized by having specific binding activity for integrin $\alpha 4\beta 1$ of at least about $1 \times 10^5 M^{-1}$, more preferably at least about $1 \times 10^6 M^{-1}$, and yet more preferably at least about $1 \times 10^7 M^{-1}$.

Those skilled in the art know how to make polyclonal and monoclonal antibodies that are specific to a desirable polypeptide. For example, monoclonal antibodies may be generated by immunizing an animal (*e.g.*, mouse, rabbit, *etc.*) with a desired antigen and the spleen cells from the immunized animal are immortalized, commonly by fusion with a myeloma cell.

Immunization with antigen may be accomplished in the presence or absence of an adjuvant (*e.g.*, Freund's adjuvant). Typically, for a mouse, 10 µg antigen in 50-200 µl adjuvant or aqueous solution is administered per mouse by subcutaneous, intraperitoneal or intra-muscular routes. Booster immunization may be given at intervals (*e.g.*, 2-8 weeks). The final boost is given approximately 2-4 days prior to fusion and is generally given in aqueous form rather than in adjuvant.

Spleen cells from the immunized animals may be prepared by teasing the spleen through a sterile sieve into culture medium at room temperature, or by gently releasing the

spleen cells into medium by pressure between the frosted ends of two sterile glass microscope slides. The cells are harvested by centrifugation (400 x g for 5 min.), washed and counted.

Spleen cells are fused with myeloma cells to generate hybridoma cell lines. Several mouse myeloma cell lines which have been selected for sensitivity to hypoxanthine-aminopterin-thymidine (HAT) are commercially available and may be grown in, for example, Dulbecco's modified Eagle's medium (DMEM) (Gibco BRL) containing 10-15% fetal calf serum. Fusion of myeloma cells and spleen cells may be accomplished using polyethylene glycol (PEG) or by electrofusion using protocols that are routine in the art. Fused cells are distributed into 96-well plates followed by selection of fused cells by culture for 1-2 weeks in 0.1 ml DMEM containing 10-15% fetal calf serum and HAT. The supernatants are screened for antibody production using methods well known in the art. Hybridoma clones from wells containing cells that produce antibody are obtained (*e.g.*, by limiting dilution). Cloned hybridoma cells (4-5 x 10^6) are implanted intraperitoneally in recipient mice, preferably of a BALB/c genetic background. Sera and ascites fluids are typically collected from mice after 10-14 days.

The invention also contemplates humanized antibodies that are specific for at least a portion of integrin $\alpha4\beta1$ and/or its ligands. Humanized antibodies may be generated using methods known in the art, including those described in U.S. Patent Numbers 5,545,806; 5,569,825 and 5,625,126, the entire contents of which are incorporated by reference. Such methods include, for example, generation of transgenic non-human animals which contain human immunoglobulin chain genes and which are capable of expressing these genes to produce a repertoire of antibodies of various isotypes encoded by the human immunoglobulin genes.

In a preferred embodiment, the antibody is specific for (*i.e.*, specifically binds to) integrin $\alpha4\beta1$ and/or a portion thereof. While the invention is illustrated using antibodies to the C-terminus of fibronectin and to integrin $\alpha4\beta1$, and using exemplary peptide antagonists to integrin $\alpha4\beta1$, the invention is not limited to the use of these particular agents. Rather, the invention expressly includes any agent which inhibits the specific binding of integrin $\alpha4\beta1$ to one or more integrin $\alpha4\beta1$ ligands. In one preferred embodiment, the anti-integrin $\alpha4\beta1$ antibody binds integrin $\alpha4\beta1$ with at least 2 times greater, preferably at least 5 times greater, more preferably at least 10 times greater, and yet more preferably at least 100 times greater, affinity than it binds another integrin, for example, aVβ3 and/or aVβ5. Anti-integrin $\alpha4\beta1$ antibodies include, without limitation, mouse anti-human integrin $\alpha4\beta1$ antibodies such as HP2/1, HP1/3, HP 1/1, HP1/7, HP2/4 (Sanchez-Madrid *et al.* (1986) Eur. J. Immunol. 16, 1342-1349), ALC1/4.1, ALC 1/5.1 (Munoz *et al.* (1997) Biochem J., 327, 27-733), 44H6 (Quackenbush *et al.* (1985) J. Immunol. 134: 1276-1285), P1H4, P4C2,

P4G9 (Wayner *et al.* (1998) J. Cell Biol. 109:1321), 9C10 (Kinashi *et al.* (1994) Blood Cells 20: 25 - 44)), 9F10 (Hemler *et al.* (1987) J. Biol. Chem. 262: 11478), B5G10 (Hemler *et al.* (1987) J. Biol. Chem. 262, 3300-3309), 15/7 (Yednock *et al.* (1995) J. Biol. Chem. 270:28740-28750), SG/73 (Miyake *et al.* (1992) J. Cell Biol., 119, 653-662). Also included within the scope of this invention are humanized anti-human integrin $\alpha4\beta1$ antibodies, such as "ANTEGREN™" (also known as natalizumab) (Tubridy *et al.* (1999) Neurology 53(3):466-72, Sheremata *et al.* (1999) Neurology 52: No.5, March 23 1999, and Lin *et al.* (1998) Current Opinion in Chemical Biology 2:453-457) and the chimeric antibodies disclosed by Newman *et al.*, U.S. patent No. 5,750,105, the contents of which are incorporated by reference; rat anti-mouse integrin $\alpha4\beta1$ antibodies such as PS/2 (Chisholm *et al.* (1993) European J. Immunol 23: 682-688); mouse anti-rat $\alpha4\beta1$ antibodies such as TA-2 (Issekutz (1991) J. Immunol 147:4178-4184); and rat anti-mouse $\alpha4\beta1$ antibodies such as R1-2 (Holzmann *et al.* (1989) Cell 56: 37 - 46).

In another preferred embodiment, the antibody is specific for VCAM and/or a portion thereof. In a more preferred embodiment, the anti-VCAM antibody inhibits the binding of VCAM to $\alpha4\beta1$ integrin but not to other integrins. Exemplary antibodies include, for example, 4B2 and 1E10, P1B8, and P3C4 (Needham *et al.* (1994) Cell Adhes. Commun. 2:87-99; Dittel *et al.* (1993) Blood 81:2272-2282), and the chimeric antibodies disclosed by Newman *et al.*, U.S. patent No. 5,750,105, the contents of which are incorporated by reference.

In yet another preferred embodiment, the antibody is specific for fibronectin and/or a portion thereof. In a more preferred embodiment, the anti-VCAM antibody inhibits the binding of VCAM to $\alpha4\beta1$ integrin but not to other integrins. Such antibodies include, without restriction, antibodies against the major and minor integrin $\alpha4\beta1$-binding sites in the C-terminal region of fibronectin, and antibodies against neighboring heparin binding sites that interfere with binding of integrin $\alpha4\beta1$ to fibronectin. Exemplary antibodies include P1F11 and P3D4 (Garcia-Pardo *et al.* (1992) Biochemical and Biophysical Research Communications 186(1):135-42); and the antibodies 20E10, 21E5, 9E9, 16E6, 19B7, 26G10, 30B6, 36C9, and 39B6 (Mostafavi-Pour *et al.* (2001) Matrix Biology 20(1):63-73).

2. Peptides

In an alternative embodiment, the agent which inhibits the specific binding of integrin $\alpha4\beta1$ to one or more of its ligands is a peptide, such as the exemplary peptide EILDVPST (SEQ ID NO:22) which inhibits integrin $\alpha4\beta1$ binding to its ligand (WO 03/019136 A3 to Varner). The term "peptide" as used herein is used broadly to refer to at least two amino acids and/or amino acid analogs that are covalently linked by a peptide bond and/or an analog of a peptide bond. The term peptide includes oligomers and

polymers of amino acids and/or amino acid analogs. The term peptide also includes molecules which are commonly referred to as peptides, which generally contain from about two to about twenty amino acids. The term peptide also includes molecules which are commonly referred to as polypeptides, which generally contain from about twenty to about fifty amino acids. The term peptide also includes molecules which are commonly referred to as proteins, which generally contain from about fifty to about 3000 amino acids. The amino acids of the peptide antagonists may be L-amino acids and/or D-amino acids.

The terms "derivative" or "modified" when in reference to a peptide mean that the peptide contains at least one derivative amino acid. A "derivative" of an amino acid and a "modified" amino acid are chemically modified amino acids. Derivative amino acids can be "biological" or "non-biological" amino acids. Chemical derivatives of one or more amino acid members may be achieved by reaction with a functional side group. Illustrative derivatized molecules include for example those molecules in which free amino groups have been derivatized to form amine hydrochlorides, p-toluene sulfonyl groups, carboxybenzoxy groups, t-butyloxycarbonyl groups, chloroacetyl groups and/or formyl groups. Free carboxyl groups may be derivatized to form salts, methyl and ethyl esters and/or other types of esters and hydrazides. Free hydroxyl groups may be derivatized to form O-acyl and/or O-alkyl derivatives. The imidazole nitrogen of histidine may be derivatized to form N-im-benzylhistidine. Also included as chemical derivatives are those peptides that contain naturally occurring amino acid derivatives of the twenty standard amino acids. For example, 4-hydroxyproline may be substituted for proline; 5-hydroxylysine may be substituted for lysine; 3-methylhistidine may be substituted for histidine; homoserine may be substituted for serine; and ornithine for lysine. Other included modifications are amino terminal acylation (*e.g.*, acetylation or thioglycolic acid amidation), terminal carboxylamidation (*e.g.*, with ammonia or methylamine), and similar terminal modifications. Terminal modifications are useful, as is well known, to reduce susceptibility by proteinase digestion and therefore to prolong the half-life of the peptides in solutions, particularly in biological fluids where proteases may be present. Exemplary modified amino acids include, without limitation, 2-Aminoadipic acid, 3-Aminoadipic acid, beta-Alanine, beta-Aminopropionic acid, 2-Aminobutyric acid, 4-Aminobutyric acid, piperidinic acid, 6-Aminocaproic acid, 2-Aminoheptanoic acid, 2-Aminoisobutyric acid, 3-Aminoisobutyric acid, 2-Aminopimelic acid, 2,4-Diaminobutyric acid, Desmosine, 2,2'-Diaminopimelic acid, 2,3-Diaminopropionic acid, N-Ethylgilycine, N-Ethylasparagine, Hydroxylysine, allo-Hydroxylysine, 3-Hydroxyproline, 4-Hydroxyproline, Isodesmosine, allo-Isoleucine, N-Methylglycine, sarcosine, N-Methylisoleucine, N-Methylavaline, Norvaline, Norleucine, and Ornithine. Derivatives also include peptides containing one or more additions or deletions, as long as the requisite activity is maintained.

The amino acids of the peptides are contemplated to include biological amino acids as well as non-biological amino acids. The term "biological amino acid" refers to any one of the known 20 coded amino acids that a cell is capable of introducing into a polypeptide translated from an mRNA. The term "non-biological amino acid" refers to an amino acid that is not a biological amino acid. Non-biological amino acids are useful, for example, because of their stereochemistry or their chemical properties. The non-biological amino acid norleucine, for example, has a side chain similar in shape to that of methionine. However, because it lacks a side chain sulfur atom, norleucine is less susceptible to oxidation than methionine. Other examples of non-biological amino acids include aminobutyric acids, norvaline and allo-isoleucine, that contain hydrophobic side chains with different steric properties as compared to biological amino acids.

Peptides that are useful in the instant invention may be synthesized by several methods, including chemical synthesis and recombinant DNA techniques. Synthetic chemistry techniques, such as solid phase Merrifield synthesis are preferred for reasons of purity, freedom from undesired side products, ease of production, *etc.* A summary of the techniques available are found in several references, including Steward *et. al.*, Solid Phase Peptide Synthesis, W. H. Freeman, Co., San Francisco (1969); Bodanszky, et. al., Peptide Synthesis, John Wiley and Sons, Second Edition (1976); J. Meienhofer, Hormonal Proteins and Peptides, 2: 46, Academic Press (1983); Merrifield, Adv. Enzymol. 32: 221-96 (1969); Fields *et. al.*, Intl. Peptide Protein Res., 35: 161-214 (1990), and U.S. Pat. No. 4,244,946 for solid phase peptide synthesis; and Schroder *et al.*, The Peptides, Vol 1, Academic Press (New York) (1965) for classical solution synthesis. Protecting groups usable in synthesis are described as well in Protective Groups in Organic Chemistry, Plenum Press, New York (1973). Solid phase synthesis methods consist of the sequential addition of one or more amino acid residues or suitably protected amino acid residues to a growing peptide chain. Either the amino or carboxyl group of the first amino acid residue is protected by a suitable selectively removable protecting group. A different, selectively removable protecting group is utilized for amino acids containing a reactive side group such as lysine.

The resultant linear peptides may then be reacted to form their corresponding cyclic peptides. A method for cyclizing peptides is described in Zimmer *et.al.*, Peptides, 393-394 (1992), ESCOM Science Publishers, B.V., 1993. To cyclize peptides containing two or more cysteines through the formation of disulfide bonds, the methods described by Tam *et al.*, J. Am. Chem..Soc., 113: 6657-6662 (1991); Plaue, Int. J. Peptide Protein Res., 35: 510-517 (1990); Atherton, J. Chem. Soc. Trans. 1: 2065 (1985); and B. Kamber *et. al.*, Helv. Chim. Acta 63: 899 (1980) are useful. Polypeptide cyclization is a useful modification to generate modified peptides (*e.g.*, peptidomimetics) because of the stable structures formed by cyclization and in view of the biological activities observed for cyclic peptides.

Alternatively, selected compounds of the present invention are produced by expression of recombinant DNA constructs prepared in accordance with well-known methods once the peptides are known. Such production can be desirable to provide large quantities or alternative embodiments of such compounds. Production by recombinant means may be more desirable than standard solid phase peptide synthesis for peptides of at least 8 amino acid residues. The DNA encoding the desired peptide sequence is preferably prepared using commercially available nucleic acid synthesis methods. Following these nucleic acid synthesis methods, DNA is isolated in a purified form that encodes the peptides. Methods to construct expression systems for production of peptides in recombinant hosts are also generally known in the art. Preferred recombinant expression systems, when transformed into compatible hosts, are capable of expressing the DNA encoding the peptides. Other preferred methods used to produce peptides comprise culturing the recombinant host under conditions that are effective to bring about expression of the encoding DNA to produce the peptide of the invention and ultimately to recover the peptide from the culture.

Expression can be effected in prokaryotic and eukaryotic hosts. The prokaryotes are most frequently represented by various strains of *E. coli*. However, other microbial strains may also be used, such as bacilli, for example *Bacillus subtilis*, various species of *Pseudomonas*, or other bacterial strains. In such prokaryotic systems, plasmid vectors that contain replication sites and control sequences derived from a species compatible with the host are used. For example, a workhorse vector for *E. coli* is pBR322 and its derivatives. Commonly used prokaryotic control sequences, which contain promoters for transcription initiation, optionally with an operator, along with ribosome binding-site sequences, include such commonly used promoters as the beta-lactamase (penicillinase) and lactose (lac) promoter systems, the tryptophan (trp) promoter system, and the lambda-derived P_L promoter and N-gene ribosome binding site. However, any available promoter system compatible with prokaryote expression is suitable for use.

Expression systems useful in eukaryotic hosts comprise promoters derived from appropriate eukaryotic genes. A class of promoters useful in yeast, for example, includes promoters for synthesis of glycolytic enzymes (*e.g.*, those for 3-phosphoglycerate kinase). Other yeast promoters include those from the enolase gene or the Leu2 gene obtained from YEp13. Suitable mammalian promoters include the early and late promoters from SV40 or other viral promoters such as those derived from polyoma, adenovirus II, bovine papilloma virus or avian sarcoma viruses. Suitable viral and mammalian enhancers may also be used. In the event plant cells are used as an expression system, the nopaline synthesis promoter, for example, is appropriate.

Once the expression systems are constructed using well-known restriction and

ligation techniques, transformation of appropriate host cells is done using standard techniques appropriate to such cells. The cells containing the expression systems are cultured under conditions appropriate for production of the peptides, and the peptides are then recovered and purified.

In a preferred embodiment, the agent that specifically binds integrin α4β1 finds use in methods of the invention where the peptide binds to integrin α4β1 with at least about a two-fold greater, more preferably at least about five-fold greater, even more preferably at least about ten-fold greater, and most preferably at least about one hundred-fold greater, specificity for integrin α4β1 than for another integrin such as αVβ3. As such, the various RGD and RLD containing peptides that have been identified based on their relatively high binding affinity for integrin αVβ3 or for integrin αVβ5 (PCT/US94/13542) are not considered peptide antagonists of integrin α4β1 binding to its ligand, as defined herein.

Exemplary peptides which inhibit the specific binding of integrin α4β1 to one or more of its ligands include, without limitation, CS-1 fibronectin and fragments of CS-1 fibronectin, such as DELPQLVTLPHPNLHGPEILDVPST (SEQ ID NO:23), HGPEILDVPST (SEQ ID NO:24), and EILDV (SEQ ID NO:25) (Wayner *et al.*, J. Cell Biol. (1989) 109(3):1321-30); LDVP (SEQ ID NO:26) (Clements *et al.*, J. Cell Sci. (1994) 107 (Pt 8):2127-35), LDV (SEQ ID NO:27) (Wayner *et al.*, J. Cell Biol. (1992) 116(2):489-97); IDAP (SEQ ID NO:28) and RDV (SEQ ID NO:29) (Clements *et al.*, J. Cell Sci. (1994) 107 (Pt 8):2127-35); GPEYLDVP (SEQ ID NO:30) (Bochner *et al.*, J. Exp. Med. (1991) 173(6):1553-7); (X)C*DPC* (SEQ ID NO:40) where X is any amino acid or modified amino acid, (X) C*(X)PC* (SEQ ID NO:31) where X is any amino acid, RC*DPC* (SEQ ID NO:32), C*WLDVC* (SEQ ID NO:33), YC*APC* (SEQ ID NO:34) and YC*DPC* (SEQ ID NO:35), and phenyacyl-C*DfC* (SEQ ID NO:36) (where "f" is D-Phe) (Jackson *et al.*, J. Med. Chem. (1997) 40(21):3359-68); RC*D(ThioP)C* (SEQ ID NO:37) (Nowlin *et al.*, J. Biol. Chem. (1993) Sep 25, 268(27):20352-9); 9-fluorenecarboxylRC*D(ThioP)C* (SEQ ID NO:38) (Cardarelli *et al.*, J. Biol. Chem. (1994) 269(28):18668-73); EGYYGNYGVYA (SEQ ID NO:39) and C*YYGNC* (SEQ ID NO:97) where * indicates cyclization points; and modifications thereof (Thorsett *et al.*, Inhibitors of leukocyte adhesion (1996) WO9602644); 1-adamantaneacetyl-Cys-Gly-Arg-Gly-Asp-Ser-Pro-Cys (SEQ ID NO:41) (Cardarelli *et al.*, J. Biol. Chem. (1994) 269(28):18668-73). Other exemplary peptides include snake disintegrins, which are exemplified by, but not limited to, EC3 from *Echis carinatus*, EC3B which is a subunit of EC3 and which has the sequence NSVHPCCDPVTCEPREGEHCISGPCCRNCKFLNAGTICKRAMLDGLNDYCTGKSSD CPRNRYKGKED (SEQ ID NO:42), MLDG (SEQ ID NO:43), a peptide fragment of EC3; and modifications thereof (Brando *et al.*, Biochem. Biophys. Res. Commun. (2000)

267(1):413-417, and Marcinkiewicz *et al.*, J. Biol. Chem. (1999) 274(18):1 2468-73); soluble VCAM (Rose *et al.* (2000) Blood 95:602-609); soluble VCAM fragments (Dudgeon *et al.*, Eur. J. Biochem. (1994) 226(2):517-23); VCAM peptide sequences RTQIDSPLN (SEQ ID NO:44), TQIDSP (SEQ ID NO:45), QIDS (SEQ ID NO:46), IDSP (SEQ ID NO:47) and KLEK (SEQ ID NO:48) (Clements *et al.*, J. Cell Sci. (1994) 107 (Pt 8): 2127-35).

Further exemplary modified peptides which inhibit the specific binding of integrin α4β1 to one or more of its ligands include a peptidomimetic (*i.e.*, an organic molecules that mimics the structure of a peptide); or a peptoid such as a vinylogous peptoid. Examples of cyclic peptides and peptidomimetics which are within the scope of the invention include, without limitation, those which are based on the peptide structure GPEYLDVP (SEQ ID NO:49), such as the compound named TBC722 (Kogan *et al.*, WO9600581), based on the peptide structure LDVP (SEQ ID NO:50) including phenylacetyl LDFp (Arrhenius *et al.*, WO9515973; Arrhenius *et al.*, WO9606108), based on the peptide structure ILDV (SEQ ID NO:51) (Dutta, WO9702289), BIO1211 (4-(2-methylphenylluriedo) phenylacetyl LDVP) BIO1272 (Lin *et al.*, WO9200995; Lin *et al.*, WO9622966), CY9652 a CS-1 peptidomimetic, TBC3342, ZD-7349 (Curley *et al.* (1999) Cell. Mol. Life Sci., 56:427-441); and others (EP-842943-A2, WO9842656-A1, WO9620216-A1, WO9600581-A1, Souers *et al.* (1998) Bioorg. Med. Chem. Lett., 8:2297-2302). Exemplary peptides and modified peptides are illustrated in Figure 5 (see, Lin *et al.* (1999) J. Med. Chem., 42:920-934), Figure 6 (*See*, Lin *et al.* (1998) Curr. Opin. Chem. Biol., 2:453-457), and Figure 7 (*See*, Souers *et al.* (1998) Bioorg. Med. Chem. Lett., 8:2297-2302). Methods for generating libraries of mimetics and for evaluating the library of mimetics for inhibiting the binding of receptors to their ligands are known in the art (Souers *et al.* (1998) *supra*).

Other peptides useful as α4β1 antagonists that reduce angiogenesis can be purchased from commercial sources, and can be identified by screening libraries of peptides, which can be prepared using well known methods of chemical synthesis (Koivunen *et al.* J. Cell Biol., 124: 373-380 (1994)). For example, peptide agonists of integrin α4β1 other than those specifically disclosed herein may be identified using methods known in the art, such as by panning phage-display peptide libraries as described in U.S. Patent No. 5,780,426 to Palladino *et al.*, the entire contents of which are herein incorporated by reference. For example, phage-display peptide libraries are panned with the integrin α4β1 receptor attached to a solid support, such as small diameter (1 μm) polystyrene latex beads. Phage selected by this method can then be tested for specific binding to integrin α4β1 via ELISA or other immunologically-based assays. Individual peptide sequences are then determined via sequencing of phage DNA. Further analysis of the minimal peptide sequence required for binding can be assessed via deletion and site-directed mutagenesis, followed by testing

of the phage for binding to integrin α4β1 via ELISA. Since the identified peptide candidates are fused to the major phage coat protein, soluble peptides are then chemically synthesized and the activity of these free peptides are tested in various *in vitro* and *in vivo* assays for the ability to act as antagonists of the integrin α4β1 receptor.

3. Nucleic Acid Sequences

In an alternative embodiment, the agent that inhibits the specific binding of α4β1 to one or more of its ligands is a nucleic acid sequence. The terms "nucleic acid sequence" and "nucleotide sequence" as used herein refer to two or more nucleotides that are covalently linked to each other. Included within this definition are oligonucleotides, polynucleotide, and fragments and/or portions thereof, DNA and/or RNA of genomic and/or synthetic origin which may be single- or double-stranded, and represent the sense or antisense strand. Nucleic acid sequences that are particularly useful in the instant invention include, without limitation, antisense sequences and ribozymes. The nucleic acid sequences are contemplated to bind to genomic DNA sequences or RNA sequences that encode integrin α4β1 or one or more of its ligands, thereby inhibiting the binding of integrin α4β1 with one or more of its ligands. Antisense and ribozyme sequences may be delivered to cells by transfecting the cell with a vector that expresses the antisense nucleic acid or the ribozyme as an mRNA molecule. Alternatively, delivery may be accomplished by entrapping ribozymes and antisense sequences in liposomes.

a. Antisense Sequences

Antisense sequences have been successfully used to inhibit the expression of several genes (Markus-Sekura (1988) Anal. Biochem. 172:289-295; Hambor *et al.* (1988) J. Exp. Med. 168:1237-1245; and patent EP 140 308), including the gene encoding VCAM1, one of the integrin α4β1 ligands (U.S. Patent No. 6,252,043, incorporated in its entirety by reference). The terms "antisense DNA sequence" and "antisense sequence" as used herein interchangeably refer to a deoxyribonucleotide sequence whose sequence of deoxyribonucleotide residues is in reverse 5' to 3' orientation in relation to the sequence of deoxyribonucleotide residues in a sense strand of a DNA duplex. A "sense strand" of a DNA duplex refers to a strand in a DNA duplex that is transcribed by a cell in its natural state into a "sense mRNA." Sense mRNA generally is ultimately translated into a polypeptide. Thus, an "antisense DNA sequence" is a sequence which has the same sequence as the non-coding strand in a DNA duplex, and which encodes an "antisense RNA" (*i.e.*, a ribonucleotide sequence whose sequence is complementary to a "sense mRNA" sequence). The designation (-) (*i.e.*, "negative") is sometimes used in reference to the antisense strand, with the designation (+) sometimes used in reference to the sense (*i.e.*,

"positive") strand. Antisense RNA may be produced by any method, including synthesis by splicing an antisense DNA sequence to a promoter that permits the synthesis of antisense RNA. The transcribed antisense RNA strand combines with natural mRNA produced by the cell to form duplexes. These duplexes then block either the further transcription of the mRNA or its translation, or promote its degradation.

Any antisense sequence is contemplated to be within the scope of this invention if it is capable of reducing the level of expression of integrin α4β1 and/or one or more of its ligands (*e.g.*, VCAM and fibronectin) to a quantity which is less than the quantity of integrin α4β1 or integrin α4β1 ligand expression in a control tissue which is (a) not treated with the antisense integrin α4β1 or integrin α4β1 ligand sequence, (b) treated with a sense integrin α4β1 or integrin α4β1 ligand sequence, or (c) treated with a nonsense sequence.

The terms "reducing the level of expression of integrin α4β1 or integrin α4β1 ligand," "diminishing integrin α4β1 or integrin α4β1 ligand expression" and grammatical equivalents thereof, refer to reducing the level of integrin α4β1 or integrin α4β1 ligand expression to a quantity which is preferably 20% less than the quantity in a control tissue, more preferably is 50% less than the quantity in a control tissue, yet more preferably is 90% less than the quantity in a control tissue, and most preferably is at the background level of, or is undetectable by, a Western blot analysis of integrin α4β1 or integrin α4β1 ligand, by immunofluorescence for detection of integrin α4β1 or integrin α4β1 ligand, by reverse transcription polymerase chain (RT-PCR) reaction for detection of integrin α4β1 or integrin α4β1 ligand mRNA, or by *in situ* hybridization for detection of integrin α4β1 or integrin α4β1 ligand mRNA. When a background level or undetectable level of integrin α4β1 or integrin α4β1 ligand peptide or mRNA is measured, this may indicate that integrin α4β1 or integrin α4β1 ligand is not expressed. A reduced level of integrin α4β1 or integrin α4β1 ligand need not, although it may, mean an absolute absence of expression of integrin α4β1 or integrin α4β1 ligand. The invention does not require, and is not limited to, antisense integrin α4β1 or integrin α4β1 ligand sequences that eliminate expression of integrin α4β1 or integrin α4β1 ligand.

Antisense integrin α4β1 or integrin α4β1 ligand sequences capable of reducing the level of integrin α4β1 expression include, for example, sequences which are capable of hybridizing with at least a portion of integrin α4β1 cDNA or integrin α4β1 ligand cDNA under high stringency or medium stringency conditions. Antisense integrin α4β1 sequences and antisense integrin α4β1 ligand sequences within the scope of this invention may be designed using approaches known in the art. In a preferred embodiment, the antisense integrin α4β1 sequences and antisense integrin α4β1 ligand sequences are designed to be hybridizable to integrin α4β1 mRNA or to integrin α4β1 ligand mRNA which is encoded by the coding region of the integrin α4β1 gene and the integrin α4β1

ligand gene, respectively. Alternatively, antisense integrin α4β1 or integrin α4β1 ligand sequences may be designed to reduce transcription by hybridizing to upstream nontranslated sequences, thereby preventing promoter binding to transcription factors.

In a preferred embodiment, the antisense oligonucleotide sequences of the invention range in size from about 8 to about 100 nucleotide residues. In yet a more preferred embodiment, the oligonucleotide sequences range in size from about 8 to about 30 nucleotide residues. In a most preferred embodiment, the antisense sequences have 20 nucleotide residues.

However, the invention is not intended to be limited to the number of nucleotide residues in the oligonucleotide sequence disclosed herein. Any oligonucleotide sequence that is capable of reducing expression of integrin α4β1 or of integrin α4β1 ligand is contemplated to be within the scope of this invention. For example, oligonucleotide sequences may range in size from about 3 nucleotide residues to the entire integrin α4β1 or integrin α4β1 ligand cDNA sequence. The art skilled know that the degree of sequence uniqueness decreases with decreasing length, thereby reducing the specificity of the oligonucleotide for the integrin α4β1 mRNA, or integrin α4β1 ligand mRNA.

The antisense oligonucleotide sequences that are useful in the methods of the instant invention may comprise naturally occurring nucleotide residues as well as nucleotide analogs. Nucleotide analogs may include, for example, nucleotide residues that contain altered sugar moieties, altered inter-sugar linkages (*e.g.*, substitution of the phosphodiester bonds of the oligonucleotide with sulfur-containing bonds, phosphorothioate bonds, alkyl phosphorothioate bonds, N-alkyl phosphoramidates, phosphorodithioates, alkyl phosphonates and short chain alkyl or cycloalkyl structures), or altered base units. Oligonucleotide analogs are desirable, for example, to increase the stability of the antisense oligonucleotide compositions under biologic conditions since natural phosphodiester bonds are not resistant to nuclease hydrolysis. Oligonucleotide analogs may also be desirable to improve incorporation efficiency of the oligonucleotides into liposomes, to enhance the ability of the compositions to penetrate into the cells where the nucleic acid sequence whose activity is to be modulated is located, in order to reduce the amount of antisense oligonucleotide needed for a therapeutic effect thereby also reducing the cost and possible side effects of treatment.

Antisense oligonucleotide sequences may be synthesized using any of a number of methods known in the art, as well as using commercially available services (*e.g.*, Genta, Inc.). Synthesis of antisense oligonucleotides may be performed, for example, using a solid support and commercially available DNA synthesizers. Alternatively, antisense oligonucleotides may also be synthesized using standard phosphoramidate chemistry techniques. For example, it is known in the art that for the generation of phosphodiester

linkages, the oxidation is mediated via iodine, while for the synthesis of phosphorothioates, the oxidation is mediated with 3H-1,2-benzodithiole-3-one,1,-dioxide in acetonitrile for the step-wise thioation of the phosphite linkages. The thioation step is followed by a capping step, cleavage from the solid support, and purification on HPLC, *e.g.*, on a PRP-1 column and gradient of acetonitrile in triethylammonium acetate, pH 7.0.

In one embodiment, the antisense DNA sequence is an "integrin α4β1 antisense DNA sequence" (*i.e.*, an antisense DNA sequence which is designed to bind with at least a portion of the integrin α4β1 genomic sequence or with integrin α4β1 mRNA). The design of integrin α4β1 antisense DNA sequences is facilitated by the availability of the sequences for the integrin α4 subunit cDNA (Figures 8 and 9), and integrin β1 cDNA (Figure 10). Particularly preferred antisense sequences are those which hybridize with genomic DNA or with RNA encoding a portion of integrin α4β1 which is involved in the specific binding with one or more of its ligands. Such integrin α4β1 portions are exemplified by, but not limited to, the sequences (see Figure 1) which comprises the sequence IVTCGHRWKNIFYIKNENKLPTGGCYGVPPDLRTELSKRIAPCYQDYVKKFGENFAA SCQAGISSFYTKDLIVMGAPGSSYWTGSLFVYNITTNKYKAFLDKQNQVKFGSYLG YSVGAGHFRSQHTTEVVGGAPQHEQIGKAYIFSIDEKELNILHEMKGKK (SEQ ID NO:10) (from amino acid 141 to amino acid 301), GHRWKN IFYIKNENKLPTGG (SEQ ID NO:11) (from amino acid 145 to amino acid 164), YQDYVKKFGENFAS (SEQ ID NO:12) (from amino acid 184 to amino acid 197), SYWTGS (SEQ ID NO:13) (from amino acid 186 to amino acid 224), GGAPQHEQIGK (SEQ ID NO:14) (from amino acid 270 to amino acid 280), YNVDTES ALLYQGPHNT IFGYSVVLHS HGANRWLLVG APTANWLANA SVINP (SEQ ID NO:54) (from amino acid 34 to amino acid 85), GRPYNVDTESALLYQGPHNTLFGYSVVLHSHGANRWLLVG APTANWLANASVINPGAIYR (SEQ ID NO:55), GVPTGRPYNVDTESAL LYQGPHNT LFGYSVVLHSHGANRWLLVGAPTANWLANASVI NPGAIYRCRIGKNPGQT (SEQ ID NO:56), IVTCGHRWKNIFYIKNENKLPTGGCYG (SEQ ID NO:57), GHRWKNIFYIKNENKLPTGGCYGVPPDLRTELSK (SEQ ID NO:58), APCYQDYVKKFGENFAS (SEQ ID NO:59), CYQDYVKKFGENFASCQA GISSFYTKDL (SEQ ID NO:60), GSSYWTGSLFVYNI (SEQ ID NO:61), RSQHTTEVVGGAPQHEQIGK (SEQ ID NO:62), GGAPQHEQIGKAYIFSIDEKEL (SEQ ID NO:63), and/or GGAPQHEQIGKA (SEQ ID NO:64).

In another embodiment, the antisense DNA sequence is a "vascular cell adhesion molecule antisense DNA sequence," *i.e.*, and antisense DNA sequence which is designed to bind with at least a portion of the VCAM genomic sequence or with VCAM mRNA. The selection and design of these antisense sequences is made possible by the availability of VCAM cDNA sequences (Figure 11). Exemplary preferred antisense sequences are those

which hybridize with genomic DNA or with RNA encoding a portion of VCAM (Figure 3A, GenBank Accession Nos. P19320) which is involved in the specific binding of VCAM with integrin α4β1. Examples of at least a portion of VCAM comprise the amino acid sequence RTQIDSPLNG (SEQ ID NO:15) (from amino acid 60 to amino acid 69); RTQIDSPLSG (SEQ ID NO:16) (from amino acid 348 to amino acid 357), KLEK (SEQ ID NO:17) (from amino acid 103 to amino acid 106, and from amino acid 391 to amino acid 394), RTQIDSPLNG (SEQ ID NO:15), RTQIDSPLSG (SEQ ID NO:16), KLEK (SEQ ID NO:17), WRTQIDSPLNGK (SEQ ID NO:65), SWRTQIDSPLNGKV (SEQ ID NO:66), SWRTQIDSPLNGKVT (SEQ ID NO:67), PFFSWRTQIDSPLNGKVTNE (SEQ ID NO:68), SRKLEKGI (SEQ ID NO:69), CESRKLEKGIQV (SEQ ID NO:70), ATCESRKLEKGIQVEI (SEQ ID NO:71), LCTATCESRKLEKGIQVEIYSFPKDPE (SEQ ID NO:72), GHKKLEKGIQVEL (SEQ ID NO:73), VTCGHKKLEKGI (SEQ ID NO:74), TCGHKKLEKGIQVELYSFPRDPE (SEQ ID NO:75), PVSFENEHSYLCTVTCGHKKLEKG (SEQ ID NO:76), RTQIDSPLSGK (SEQ ID NO:77), FSWRTQIDSPLSGKVR (SEQ ID NO:78), and/or ESPSFWWRTQIDSPLSGK (SEQ ID NO:79).

In yet another embodiment, the antisense DNA sequence is a "fibronectin α4β1 antisense DNA sequence" (*i.e.*, an antisense DNA sequence which is designed to bind with at least a portion of the fibronectin genomic sequence or with fibronectin α4β1 mRNA). The selection and design of these antisense sequences is made possible by the availability of the sequence for fibronectin cDNA (Figure 12). Exemplary nucleic acid sequences which may be targeted are those which encode the following sequences shown in Figure 4, the IIICS sequence (SEPLIGRKKTDELPQLVTLPHPNLHGPE ILDVPSTVQKTPFVTHPGYDTGNGIQLPGGTSGQQPSVGQQMIFEEHGFRRTTPPTT ATPIRHRPRPYPPNVGEEIQIGHIPREDVVDYHLYPHGPGLNPNAST) (SEQ ID NO:18) from amino acid 1982 to amino acid 2111, the CS-1 sequence which contains the amino acid sequence LDV (SEQ ID NO:19) (from amino acid 2011 to amino acid 2013), the CS-5 sequence which contains the amino acid sequence REDV (SEQ ID NO:20) (from amino acid 2091 to amino acid 2093), IDAPS (SEQ ID NO:21) (from amino acid 1903 to amino acid 1907), TAIDAPSNLRDAS (SEQ ID NO:80), TAIDAPSNLRFLATTP (SEQ ID NO:81), RSSPVVIDASTAIDAPS (SEQ ID NO:82), IDAPSNLRFLATTPNSLLV (SEQ ID NO:83), IDAPSNLRFLATTPNSLLVSWQPPRARITGYIIKYE (SEQ ID NO:84), IDDVPST (SEQ ID NO:85), NLHGPEILDVPSTVQK (SEQ ID NO:86), PHPNLHGPEILDV (SEQ ID NO:87), ILDVPSTVQKTPFVTHPGYD (SEQ ID NO:88), VTLPHPNLHGPEILDVP (SEQ ID NO:89), EILDV (SEQ ID NO:90), IPREDVDY (SEQ ID NO:91), GHIPRDDVD (SEQ ID NO:92), GHIPREDV (SEQ ID NO:93), LDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHG

FRRTTPPTTATPIRHRPRPYPPNVGEEIQIGHIPREDV (SEQ ID NO:94), and/or PEILDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHGFRRTTPPTT TATPIRHRPRPYPPNVGEEIQIGHIPREDVDY (SEQ ID NO:95).

b. Ribozyme

In some alternative embodiments, the agent that inhibits the specific binding of integrin α4β1 to its ligand is a ribozyme. Ribozyme sequences have been successfully used to inhibit the expression of several genes including the gene encoding VCAM1, which is one of the integrin α4β1 ligands (U.S. Patent No. 6,252,043, incorporated in its entirety by reference).

The term "ribozyme" refers to an RNA sequence that hybridizes to a complementary sequence in a substrate RNA and cleaves the substrate RNA in a sequence specific manner at a substrate cleavage site. Typically, a ribozyme contains a "catalytic region" flanked by two "binding regions." The ribozyme binding regions hybridize to the substrate RNA, while the catalytic region cleaves the substrate RNA at a "substrate cleavage site" to yield a "cleaved RNA product." The nucleotide sequence of the ribozyme binding regions may be completely complementary or partially complementary to the substrate RNA sequence with which the ribozyme binding regions hybridize. Complete complementarity is preferred, in order to increase the specificity, as well as the turnover rate (*i.e.*, the rate of release of the ribozyme from the cleaved RNA product), of the ribozyme. Partial complementarity, while less preferred, may be used to design a ribozyme binding region containing more than about 10 nucleotides. While contemplated to be within the scope of the claimed invention, partial complementarity is generally less preferred than complete complementarity since a binding region having partial complementarity to a substrate RNA exhibits reduced specificity and turnover rate of the ribozyme when compared to the specificity and turnover rate of a ribozyme which contains a binding region having complete complementarity to the substrate RNA. A ribozyme may hybridize to a partially or completely complementary DNA sequence but cannot cleave the hybridized DNA sequence since ribozyme cleavage requires a 2'-OH on the target molecule, which is not available on DNA sequences.

The ability of a ribozyme to cleave at a substrate cleavage site may readily be determined using methods known in the art. These methods include, but are not limited to, the detection (*e.g.*, by Northern blot analysis as described herein, reverse-transcription polymerase chain reaction (RT-PCR), *in situ* hybridization and the like) of reduced *in vitro* or *in vivo* levels of RNA which contains a ribozyme substrate cleavage site for which the ribozyme is specific, compared to the level of RNA in controls (*e.g.*, in the absence of ribozyme, or in the presence of a ribozyme sequence which contains a mutation in one or both unpaired nucleotide sequences which renders the ribozyme incapable of cleaving a

substrate RNA) .

Ribozymes contemplated to be within the scope of this invention include, but are not restricted to, hammerhead ribozymes (*See e.g.*, Reddy *et al.*, U.S. Patent No. 5,246,921; Taira *et al.*, U.S. Patent No. 5,500,357, Goldberg *et al.*, U.S. Patent No. 5,225,347, the contents of each of which are herein incorporated by reference), Group I intron ribozyme (Kruger *et al.* (1982) Cell 31: 147-157), ribonuclease P (Guerrier-Takada *et al.* (1983) Cell 35: 849-857), hairpin ribozyme (Hampel *et al.*, U.S. Patent No. 5,527,895 incorporated by reference), and hepatitis delta virus ribozyme (Wu *et al.* (1989) Science 243:652-655).

A ribozyme may be designed to cleave at a substrate cleavage site in any substrate RNA so long as the substrate RNA contains one or more substrate cleavage sequences, and the sequences flanking the substrate cleavage site are known. In effect, expression *in vivo* of such ribozymes and the resulting cleavage of RNA transcripts of a gene of interest reduces or ablates expression of the corresponding gene.

For example, where the ribozyme is a hammerhead ribozyme, the basic principle of a hammerhead ribozyme design involves selection of a region in the substrate RNA which contains a substrate cleavage sequence, creation of two stretches of antisense oligonucleotides (*i.e.*, the binding regions) which hybridize to sequences flanking the substrate cleavage sequence, and placing a sequence which forms a hammerhead catalytic region between the two binding regions.

In order to select a region in the substrate RNA which contains candidate substrate cleavage sites, the sequence of the substrate RNA needs to be determined. The sequence of RNA encoded by a genomic sequence of interest is readily determined using methods known in the art. For example, the sequence of an RNA transcript may be arrived at either manually, or using available computer programs (*e.g.*, GENEWORKS, from IntelliGenetic Inc., or RNADRAW available from the internet at ole@mango.mef.ki.se), by changing the T in the DNA sequence encoding the RNA transcript to a U.

Substrate cleavage sequences in the target RNA may be located by searching the RNA sequence using available computer programs. For example, where the ribozyme is a hammerhead ribozyme, it is known in the art that the catalytic region of the hammerhead ribozyme cleaves only at a substrate cleavage site which contains a NUH, where N is any nucleotide, U is a uridine, and H is a cytosine (C), uridine (U), or adenine (A) but not a guanine (G). The U-H doublet in the NUH cleavage site does not include a U-G doublet since a G would pair with the adjacent C in the ribozyme and prevent ribozyme cleavage. Typically, N is a G and H is a C. Consequently, GUC has been found to be the most efficient substrate cleavage site for hammerhead ribozymes, although ribozyme cleavage at CUC is also efficient.

In a preferred embodiment, the substrate cleavage sequence is located in a loop

structure or in an unpaired region of the substrate RNA. Computer programs for the prediction of RNA secondary structure formation are known in the art and include, for example, "RNADRAW", "RNAFOLD" (Hofacker *et al.* (1994) Monatshefte F. Chemie 125:167-188; McCaskill (1990) Biopolymers 29:1105-1119). "DNASIS" (Hitachi), and "THE VIENNA PACKAGE."

In addition to the desirability of selecting substrate cleavage sequences which are located in a loop structure or an unpaired region of the substrate RNA, it is also desirable, though not required, that the substrate cleavage sequence be located downstream (*i.e.*, at the 3'-end) of the translation start codon (AUG or GUG) such that the translated truncated polypeptide is not biologically functional.

In a preferred embodiment, the ribozyme is an "integrin α4β1 ribozyme" (*i.e.*, a ribozyme whose substrate cleavage sequence is designed to hybridize with a portion of integrin α4β1 that is involved in the specific binding of integrin α4β1 with one or more of its ligands). Such integrin α4β1 portions are exemplified by, but not limited to, the sequences (see Figure 1) which comprises the sequence IVTCGHRWKNIFYIKNENKLPTGGCYGVPPDLRTELSKRIAPCYQDYVKKFGENFAA SCQAGISSFYTKDLIVMGAPGSSYWTGSLFVYNITTNKYKAFLDKQNQVKFGSYLG YSVGAGHFRSQHTTEVVGGAPQHEQIGKAYIFSIDEKELNILHEMKGKK (SEQ ID NO:10) (from amino acid 141 to amino acid 301), GHRWKN IFYIKNENKLPTGG (SEQ ID NO:11) (from amino acid 145 to amino acid 164), YQDYVKKFGENFAS (SEQ ID NO:12) (from amino acid 184 to amino acid 197), SYWTGS (SEQ ID NO:13) (from amino acid 186 to amino acid 224), GGAPQHEQIGK (SEQ ID NO:14) (from amino acid 270 to amino acid 280), YNVDTES ALLYQGPHNT IFGYSVVLHS HGANRWLLVG APTANWLANA SVINP (SEQ ID NO:54) (from amino acid 34 to amino acid 85), GRPYNVDTESALLYQGPHNTLFGYSVVLHSHGANRWLLVG APTANWLANASVINPGAIYR (SEQ ID NO:55), GVPTGRPYNVDTESAL LYQGPHNT LFGYSVVLHSHGANRWLLVGAPTANWLANASVI NPGAIYRCRIGKNPGQT (SEQ ID NO:56), IVTCGHRWKNIFYIKNENKLPTGGCYG (SEQ ID NO:57), GHRWKNIFYIKNENKLPTGGCYGVPPDLRTELSK (SEQ ID NO:58), APCYQDYVKKFGENFAS (SEQ ID NO:59), CYQDYVKKFGENFASCQA GISSFYTKDL (SEQ ID NO:60), GSSYWTGSLFVYNI (SEQ ID NO:61), RSQHTTEVVGGAPQHEQIGK (SEQ ID NO:62), GGAPQHEQIGKAYIFSIDEKEL (SEQ ID NO:63), and/or GGAPQHEQIGKA (SEQ ID NO:64).

In an alternative embodiment, the substrate cleavage sequence is designed to hybridize with a portion of an integrin α4β1 ligand, wherein the portion is involved in the specific binding of the ligand with integrin α4β1.

In a more preferred embodiment, the ribozyme is a "vascular cell adhesion molecule

ribozyme" (*i.e.*, a ribozyme whose substrate cleavage sequence is designed to hybridize with a portion of VCAM that is involved in the specific binding of VCAM with integrin α4β1). Exemplary portions of the ligand VCAM (Figure 3A, GenBank Accession Nos. P19320) comprise the amino acid sequence RTQIDSPLNG (SEQ ID NO:15) (from amino acid 60 to amino acid 69); RTQIDSPLSG (SEQ ID NO:16) (from amino acid 348 to amino acid 357), KLEK (SEQ ID NO:17) (from amino acid 103 to amino acid 106, and from amino acid 391 to amino acid 394), RTQIDSPLNG (SEQ ID NO:15), RTQIDSPLSG (SEQ ID NO:16), KLEK (SEQ ID NO:17), WRTQIDSPLNGK (SEQ ID NO:65), SWRTQIDSPLNGKV (SEQ ID NO:66), SWRTQIDSPLNGKVT (SEQ ID NO:67), PFFSWRTQIDSPLNGKVTNE (SEQ ID NO:68), SRKLEKGI (SEQ ID NO:69), CESRKLEKGIQV (SEQ ID NO:70), ATCESRKLEKGIQVEI (SEQ ID NO:71), LCTATCESRKLEKGIQVEIYSFPKDPE (SEQ ID NO:72), GHKKLEKGIQVEL (SEQ ID NO:73), VTCGHKKLEKGI (SEQ ID NO:74), TCGHKKLEKGIQVELYSFPRDPE (SEQ ID NO:75), PVSFENEHSYLCTVTCGHKKLEKG (SEQ ID NO:76), RTQIDSPLSGK (SEQ ID NO:77), FSWRTQIDSPLSGKVR (SEQ ID NO:78), and/or ESPSFWWRTQIDSPLSGK (SEQ ID NO:79).

In an alternative preferred embodiment, the ribozyme is a "fibronectin ribozyme" (*i.e.*, a ribozyme whose substrate cleavage sequence is designed to hybridize with a portion of fibronectin that is involved in the specific binding of fibronectin with integrin α4β1). Exemplary portions of the ligand fibronectin comprise the following sequences shown in Figure 4, the IIICS sequence (SEPLIGRKKTDELPQLVTLP HPNLHGPEILDVPSTVQKTPFVTHPGYDTGNGIQLPGGTSGQQPSVGQQMIFEEHGF RRTTPPTTATPIRHRPRPYPPNVGEEIQIGHIPREDVVDYHLYPHGPGLNPN AST) (SEQ ID NO:18) from amino acid 1982 to amino acid 2111, the CS-1 sequence which contains the amino acid sequence LDV (SEQ ID NO:19) (from amino acid 2011 to amino acid 2013), the CS-5 sequence which contains the amino acid sequence REDV (SEQ ID NO:20) (from amino acid 2091 to amino acid 2093), IDAPS (SEQ ID NO:21) (from amino acid 1903 to amino acid 1907), TAIDAPSNLRDAS (SEQ ID NO:80), TAIDAPSNLRFLATTP (SEQ ID NO:81), RSSPVVIDASTAIDAPS (SEQ ID NO:82), IDAPSNLRFLATTPNSLLV (SEQ ID NO:83), IDAPSNLRFLATTPNSLLVSWQPPRARITGYIIKYE (SEQ ID NO:84), IDDVPST (SEQ ID NO:85), NLHGPEILDVPSTVQK (SEQ ID NO:86), PHPNLHGPEILDV (SEQ ID NO:87), ILDVPSTVQKTPFVTHPGYD (SEQ ID NO:88), VTLPHPNLHGPEILDVP (SEQ ID NO:89), EILDV (SEQ ID NO:90), IPREDVDY (SEQ ID NO:91), GHIPRDDVD (SEQ ID NO:92), GHIPREDV (SEQ ID NO:93), LDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHG FRRTTPPTTATPIRHRPRPYPPNVGEEIQIGHIPREDV (SEQ ID NO:94), and/or

PEILDVPSTVQKTPFVTHPGYDTGNGIQLPGTSGQQPSVGQQMIFEEHGFRRTTPPTT TATPIRHRPRPYPPNVGEEIQIGHIPREDVDY (SEQ ID NO:95).

It is known in the art that the specificity of ribozyme cleavage for a substrate RNA molecule is determined by the sequence of nucleotides which flank the substrate cleavage site and which hybridize with the ribozyme binding regions. Thus, ribozymes can be designed to cleave at different locations within a substrate RNA molecule by altering the sequence of the binding regions that surround the ribozyme catalytic region of the ribozyme such that the binding regions hybridize with any known sequence on the substrate RNA.

In addition to varying the sequence of the binding regions to effect binding to different locations on the RNA substrate, the number of nucleotides in each of the ribozyme binding regions may also be altered in order to change the specificity of the ribozyme for a given location on the RNA substrate. The number of nucleotides in a binding region is preferably between about 5 and about 25 nucleotides, more preferably between about 11 and about 15 nucleotides, yet more preferably between about 7 nucleotides and about 10 nucleotides.

One of skill in the art appreciates that it is not necessary that the two binding regions that flank the ribozyme catalytic region be of equal length. Binding regions that contain any number of nucleotides are contemplated to be within the scope of this invention so long as the desirable specificity of the ribozyme for the RNA substrate and the desirable cleavage rate of the RNA substrate are achieved. One of skill in the art knows that binding regions of longer nucleotide sequence, while increasing the specificity for a particular substrate RNA sequence, may reduce the ability of the ribozyme to dissociate from the substrate RNA following cleavage to bind with another substrate RNA molecule, thus reducing the rate of cleavage. On the other hand, though binding regions with shorter nucleotide sequences may have a higher rate of dissociation and cleavage, specificity for a substrate cleavage site may be compromised.

It is well within the skill of the art to determine an optimal length for the binding regions of a ribozyme such that a desirable specificity and rate of cleavage are achieved. Both the specificity of a ribozyme for a substrate RNA and the rate of cleavage of a substrate RNA by a ribozyme may be determined by, for example, kinetic studies in combination with Northern blot analysis or nuclease protection assays.

In a preferred embodiment, the complementarity between the ribozyme binding regions and the substrate RNA is complete. However, the invention is not limited to ribozyme sequences in which the binding regions show complete complementarity with the substrate RNA. Complementarity may be partial, so long as the desired specificity of the ribozyme for a substrate cleavage site and the rate of cleavage of the substrate RNA are achieved. Thus, base changes may be made in one or both of the ribozyme binding regions

as long as substantial base pairing with the substrate RNA in the regions flanking the substrate cleavage sequence is maintained and base pairing with the substrate cleavage sequence is minimized. The term "substantial base pairing" means that greater than about 65%, more preferably greater than about 75%, and yet more preferably greater than about 90% of the bases of the hybridized sequences are base-paired.

It may be desirable to increase the intracellular stability of ribozymes expressed by an expression vector. This is achieved by designing the expressed ribozyme such that it contains a secondary structure (*e.g.*, stem-loop structures) within the ribozyme molecule. Secondary structures which are suitable for stabilizing ribozymes include, but are not limited to, stem-loop structures formed by intra-strand base pairs. An alternative to the use of a stem-loop structure to protect ribozymes against ribonuclease degradation is by the insertion of a stem loop at each end of the ribozyme sequence (Sioud and Drlica (1991) Proc. Natl. Acad. Sci. USA 88:7303-7307). Other secondary structures which are useful in reducing the susceptibility of a ribozyme to ribonuclease degradation include hairpin, bulge loop, interior loop, multibranched loop, and pseudoknot structure as described in "Molecular and Cellular Biology," Stephen L. Wolfe (Ed.), Wadsworth Publishing Company (1993) p. 575. Additionally, circularization of the ribozyme molecule protects against ribonuclease degradation since exonuclease degradation is initiated at either the 5'-end or 3'-end of the RNA. Methods of expressing a circularized RNA are known in the art (see, *e.g.*, Puttaraju *et al.* (1993) Nucl. Acids Res. 21:4253-4258).

Once a ribozyme with desirable binding regions, a catalytic region and nuclease stability has been designed, the ribozyme may be produced by any known means including chemical synthesis. Chemically synthesized ribozymes may be introduced into a cell by, for example, microinjection electroporation, lipofection, *etc.* In a preferred embodiment, ribozymes are produced by expression from an expression vector that contains a gene encoding the designed ribozyme sequence.

4. Other Agents

While the present invention is illustrated herein using antibody, peptide, and nucleic acid sequences that inhibit the specific binding of integrin $\alpha4\beta1$ to one or more of its ligands, the invention expressly contemplates within its scope other agents (*e.g.*, organic molecules, inorganic molecules, *etc.*) so long as the agent is capable of inhibiting the specific binding of integrin $\alpha4\beta1$ to one or more of its ligands. Such agents may be identified by screening libraries of test compounds (made as described below) using a competitive binding assay or a cell adhesion assay. In a competitive binding assay, for example, integrin $\alpha4\beta1$ is coated on plastic microtiter plates and contacted with a labeled known integrin $\alpha4\beta1$ ligand (*e.g.*, CS-1 fibronectin or VCAM). The test compounds are

tested for their ability to inhibit binding of the labeled ligand to integrin α4β1. Compounds that inhibit such binding are identified as agents that are capable of inhibiting the specific binding of integrin α4β1 to the ligand.

Alternatively, in a cell adhesion assay, a labeled known integrin α4β1 ligand (*e.g.*, CS-1 fibronectin or VCAM) is coated on culture plates, and cells which express integrin α4β1 are allowed to adhere to the ligand for 20-30 minutes in the presence of libraries of test compounds. Compounds that inhibit the binding of the integrin α4β1-expressing cells to the coating of integrin α4β1 ligand are identified as agents that inhibit the specific binding of integrin α4β1 to the ligand.

C. Integrin α4β1 Mediates Trafficking of Endothelial Progenitor Cells, As Exemplified By Endothelial Stem Cells, During Neovascularization

Bone marrow derived stem cells contribute to the repopulation of tissues undergoing repair, including vascular endothelium, smooth muscle, neurons and muscle (Asahara et al., Science. 1997 Feb 14;275(5302):964-7; Jain et al., Cancer Cell. 2003 Jun;3(6):515-6; Religa et al., Transplantation. 2002 Nov 15;74(9):1310-5; Priller et al., J Cell Biol. 2001 Nov 26;155(5):733-8; LaBarge et al., Cell. 2002 Nov 15;111(4):589-601). The mechanisms by which hematopoietic stem cells home to sites of ongoing tissue repair remain unclear. Here we show that integrin α4β1 (VLA-4) promotes the emigration of endothelial precursor cells (EPCs) from the circulation to sites of angiogenesis. During angiogenesis, integrin α4β1 promotes the attachment of EPCs to VCAM on activated endothelium and to alternatively spliced tissue (CS-1) fibronectin, which is found underlying this endothelium. Antagonists of α4β1 block the efflux of EPCs from the circulation during angiogenesis, thereby suppressing growth factor and tumor induced angiogenesis *in vivo*. Thus, α4β1 contributes to angiogenesis by regulating hematopoietic stem cell recruitment to the neovascular bed.

Neovascularization is a key component of tissue repair processes that contribute to wound healing, but when chronically stimulated, it also plays a role in pathologies such as tumor growth and inflammatory disease (Carmeliet et al., Nat Med. 2003 Jun;9(6):653-60; Carmeliet et al., Nature. 2000 Sep 14;407(6801):249-57). Neovascularization is thought to arise by at two mechanisms. Activation of quiescent endothelial cells within tissue blood vessels by angiogenic growth factors promotes the development of new blood vessels by sprouting (Carmeliet et al., Nat Med. 2003 Jun;9(6):653-60; Carmeliet et al., Nature. 2000 Sep 14;407(6801):249-57). A second mechanism involves the homing of bone marrow derived endothelial stem cells to sites of neovascularization such as ischemic limbs or tumors (Asahara et al., Science. 1997 Feb supra; Jain et al., Cancer Cell. 2003 Jun;3(6):515-6; Lyden et al., Nat Med. 2001 Nov;7(11):1194-201; Takahashi et al., Nat

Med. 1999 Apr;5(4):434-8; Kawamoto et al., Circulation. 2001 Feb 6;103(5):634-7; Hattori et al., J Exp Med. 2001 May 7;193(9):1005-14; Kalka et al., Proc Natl Acad Sci U S A. 2000 Mar 28;97(7):3422-7). These bone marrow derived stem cells can home to muscle, brain and other tissues undergoing repair whereupon they participate in tissue regeneration (Asahara et al., Science. 1997 Feb supra; Jain et al., Cancer Cell. 2003 Jun;3(6):515-6; Religa et al., Transplantation. 2002 Nov 15;74(9):1310-5; Priller et al., J Cell Biol. 2001 Nov 26;155(5):733-8; LaBarge et al., Cell. 2002 Nov 15;111(4):589-601; Lyden et al., Nat Med. 2001 Nov;7(11):1194-201; Takahashi et al., Nat Med. 1999 Apr;5(4):434-8; Kawamoto et al., Circulation. 2001 Feb 6;103(5):634-7; Hattori et al., J Exp Med. 2001 May 7;193(9):1005-14; Kalka et al., Proc Natl Acad Sci U S A. 2000 Mar 28;97(7):3422-7; Torrente et al., J Cell Biol. 2003 Aug 4;162(3):511-20). However, the mechanisms by which bone marrow derived stem cells such as EPCs exit from the circulation and enter tissues to participate in tissue repair process remain unclear.

Antagonists of integrin $\alpha4\beta1$ (antibodies, peptides, *etc.*) inhibit bone marrow derived stem cells or precursor cells from entering tissues by blocking their association with the vascular endothelium and by blocking their migration on the extracellular matrix in tissues beneath the endothelium. These antagonists can be used to block hematopoietic stem cells from participating in angiogenesis, atherosclerosis, restenosis, inflammation, cancer, and other diseases in which hematopoietic stem cells play a role. Additionally, reagents that selectively bind to $\alpha4\beta1$, such as high affinity antibodies, recombinant soluble VCAM or CS-1 fibronectin, can be used to purify hematopoietic stem cells from tissues, bone marrow, peripheral blood, cord blood, *etc.* so that they may be expanded and used further for therapeutic applications such as repair of damaged heart tissue, stimulation of angiogenesis in ischemic tissues and repair of congenital muscle defects. Finally, cytokines that upregulate VCAM on vascular endothelium may be used to encourage the entry of hematopoietic stem cells into tissues by providing a site for hematopoietic stem cells to adhere to the vascular endothelium.

Currently, bone marrow derived hematopoietic stem cells are under study for use in the repair of muscle, heart, ischemic tissues, nerves and a myriad of other imaginable applications. While researchers can show that purified or native bone marrow derived hematopoietic stem cells do enter into normal tissues and participate in tissue regeneration, generally the number of cells that make it into tissues is small. Additionally, bone marrow derived hematopoietic stem cells participate in pathological processes such as tumor growth and angiogenesis, atherosclerosis and restenosis. Data herein (such as Examples 4-15) shows identification of the molecular pathway through which these cells recognize the endothelium, adhere to it and enter into the tissue. Furthermore, we have determined several methods to inhibit or promote hematopoietic stem cell homing.

As integrin $\alpha4\beta1$ is also an effector of immune cell trafficking *in vivo*, data herein (Examples 4-15) suggest that $\alpha4\beta1$ may be expressed by "the hemangioblast," a putative precursor common to HSCs and EPC lineages. Data herein shows that integrin $\alpha4\beta1$ plays an important and unique role in tissue repair processes, by mediating the interaction of endothelial precursor cells with more established endothelium. Integrin $\alpha4\beta1$ may also play a key role in regulating endothelial sprouting from established vessels; its transient expression on neovessels may indicate a functional role early in the angiogenic process. As CD34 positive bone marrow derived stem cells are integrin $\alpha4\beta1$ positive, it is possible that this integrin regulates the trafficking of other CD34 positive stem cells into tissues during tissues repair. These data indicate that antagonists of integrin $\alpha4\beta1$ could be used to inhibit pathological angiogenesis and tumor growth as well as other pathological conditions in which hematopoietic stem cells play an important. These data also suggest that hematopoietic stem cell homing to tissues needing repair could be enhanced by stimulating the endothelium to express VCAM and by stimulating hematopoietic stem cells $\alpha4\beta1$ activity.

Little is known about the mechanisms by which hematopoietic stem cells exit from the circulation and enter into tissues. Furthermore, methods to block or enhance this process are unknown. Thus, the invention provides the only known method to block or promote hematopoietic stem cell homing to tissues. The invention is useful in blocking homing by using inhibitors of integrin $\alpha4\beta1$, which is the hematopoietic stem cell receptor for the vascular endothelium. The invention is also useful in stimulating homing by causing VCAM, the counter-receptor on endothelium, to be expressed (by applying growth factors or inflammatory cytokines to the regional vasculature).

Antibody, peptide or organic molecule inhibitors of integrin $\alpha4\beta1$ may be used in vivo to inhibit hematopoietic stem cells from entering tissues and participating in aberrant tissue repair processes, such as pathological angiogenesis in cancer, arthritis and neovascular eye disease, atherosclerosis, restenosis and others. Stimulation of VCAM expression on the endothelium of tissues needing repair may be used to promote hematopoietic stem cell homing to tissues. Finally, reagents that bind $\alpha4\beta1$ with high affinity may be used to purify or isolate hematopoietic stem cells for use in therapeutic applications.

Data herein (*e.g.*, Examples 4-15) shows that inhibiting $\alpha4\beta1$ blocks angiogenesis (growth factor and tumor induced), blocks endothelial stem cell growth in vitro, blocks endothelial stem cell attachment to endothelium in vitro and blocks endothelial stem cell recruitment to endothelium in vivo. Data herein (*e.g.*, Examples 4-15) also shows that all bone marrow derived stem cells (which may be identified by expression of the CD34 positive marker) express $\alpha4\beta1$ and are currently showing that blocking $\alpha4\beta1$ blocks

additional stem cell from adhering to endothelium and entering tissues. These studies show the feasibility of using $\alpha4\beta1$ expression, in combination with additional markers of stem cells, to isolate stem cells.

The invention is useful by exploiting inhibition of integrin $\alpha4\beta1$: Inhibition of tumor growth (by blocking angiogenesis and immune cell contributions to tumor growth), inhibition of other neovascular diseases such as arthritis, eye disease, and psoriasis, inhibition of atherosclerosis and restenosis by blocking hematopoietic stem cell contribution to these diseases.

The invention is also useful by exploiting enhancement of hematopoietic stem cell entry into tissues by inducing the expression of VCAM on endothelium, the counter receptor for $\alpha4\beta1$: enhancement of angiogenesis in ischemic disease (heart attach, diabetes), enhancement of muscle repair and nerve repair in neuromuscular diseases, enhancing other types of tissue repair. The invention is also useful for isolating hematopoietic stem cells using integrin $\alpha4\beta1$ selection.

D. Altering Hematopoietic Progenitor Cell Adhesion, Migration and Differentiation

The invention further provides methods for altering HPC adhesion and/or migration to a target tissue, and for altering HPC differentiation into a second cell type, by employing an agent that alters the specific binding of integrin $\alpha4\beta1$ to its ligand. The invention is premised at least in part on the surprising discovery that integrin $\alpha4\beta1$ (VLA-4) promotes the homing of the exemplary circulating hematopoietic stem cells to the $\alpha4\beta1$ ligands, vascular cell adhesion molecule (VCAM) and cellular fibronectin, which are expressed on neovasculature (Examples 17-24). CD34+ stem cells, which express integrin $\alpha4\beta1$, homed to sites of active neovascularization but not to normal tissues. Antagonists of integrin $\alpha4\beta1$ blocked the adhesion of the exemplary hematopoietic stem cells to endothelium *in vitro* and *in vivo* and their outgrowth into neovessels (Examples 17-24).

The term "cell adhesion" as used herein refers to the physical contacting of the cell to one or more components of the extracellular matrix (*e.g.*, fibronectin, collagens I-XVIII, laminin, vitronectin, fibrinogen, osteopontin, Del 1, tenascin, von Willebrands's factor, *etc.*), to a ligand which is expressed on the cell surface (*e.g.*, VCAM, ICAM, LI-CAM, VE-cadherin, integrin a2, integrin a3, *etc.*) and/or to another cell of the same type (*e.g.*, adhesion of an HPC to another HPC) or of a different type (*e.g.*, adhesion of an HPC to an endothelial cell, endothelial stem cell, stem cell expressing CD34, fibroblast cell, stromal cell, tumor cell, *etc.*).

The term"reducing cell adhesion" refers to reducing the level of adhesion to a quantity which is preferably 10% less than, more preferably 50% less than, yet more

preferably 75% than, even more preferably 90% less than, the quantity in a control cell, and most preferably is at the same level which is observed in a control cell. A reduced level of cell adhesion need not, although it may, mean an absolute absence of cell adhesion. The invention does not require, and is not limited to, methods that wholly eliminate cell adhesion. The level of cell adhesion may be determined using methods disclosed herein an others known in the art (*e.g.*, WO 03/019136 A3 to Varner).

The term "cell migration" as used herein refers to the translocation of a cell across one or more components of the extracellular matrix (*e.g.*, fibronectin, collagens I-XVIII, laminin, vitronectin, fibrinogen, osteopontin, Del 1, tenascin, von Willebrands's factor, *etc.*), and/or along the surface of another cell of the same type (*e.g.*, migration of an HPC along another HPC) and/or of a different cell (*e.g.*, migration of an HPC along an endothelial cell, endothelial stem cell, stem cell expressing CD34, fibroblast cell, stromal cell, tumor cell, *etc.*). Thus, "trans-endothelial migration" of a cell refers to the translocation of the cell across one or more components of the extracellular matrix and/or cells of endothelial tissue.

The term "reducing cell migration" refers to reducing the level of migration of a cell to a quantity which is preferably 10% less than, more preferably 50% less than, yet more preferably 75% less than, and even more preferably 90% less than, the quantity in a control cell, and most preferably is at the same level which is observed in a control cell. A reduced level of cell migration need not, although it may, mean an absolute absence of cell migration. The invention does not require, and is not limited to, methods that wholly eliminate cell migration. The level of cell migration may be determined using methods disclosed herein and known in the art, such as time lapse video microscopy, scratch type wound assay, and others (*e.g.*, WO 03/019136 A3 to Varner).

The "level of differentiation" when in reference to a cell of interest in a sample is a relative term that refers to the quantity per cell of interest (*e.g.*, hematopoietic progenitor cell) of expressed differentiation marker (*e.g.*, B220, CD3, CD11b, *etc.*) compared to the quantity per cell of the same marker that is expressed by a differentiated cell (*e.g.*, B cells that express the B220 marker, T-cells that express the CD3 marker, and myeloid cells that express the CD11b marker, respectively).

The term "reducing cell differentiation" refer to reducing the level of differentiation of a cell to a quantity which is preferably 10% less than, more preferably 50% less than, yet more preferably 75% less than, and even more preferably 90% less than, the quantity in a control cell, and most preferably is at the same level which is observed in a control cell. A reduced level of cell differentiation need not, although it may, mean an absolute absence of cell differentiation. The invention does not require, and is not limited to, methods that wholly eliminate cell migration. The level of cell differentiation may be determined using methods disclosed herein and known in the art.

E. Altering Hematopoietic Progenitor Cell Adhesion, Migration, and Differentiation

The invention provides methods for altering HPC adhesion, migration and/or differentiation in a subject by altering the binding of $\alpha4\beta1$ to one or more of its ligands (*e.g.*, fibronectin and VCAM) in a tissue in the subject. In one embodiment, the subject has a condition that is associated with undesirable HPC adhesion, migration, and/or differentiation, such as in angiogenic disease. The term "angiogenic disease" is used broadly herein to mean any condition characterized, at least in part, by neovascularization. In contrast, a "non-angiogenic disease" is a condition that is not associated with neovascularization. Angiogenesis includes normal angiogenesis processes (*e.g.*, scar formation during wound healing or during fertility), and angiogenesis, which is associated with a pathological condition, such as that which occurs in ocular tissue (*e.g.*, retina, macular or cornea), in skin such as occurs with psoriasis, in synovial tissue, in bone, in intestinal tissue, or in a tumor, including pathological conditions that are exemplified by, but not limited to, neoplasms, ocular diseases such as diabetic retinopathy and macular degeneration associated with neovascularization, skin diseases such as psoriasis and hemangiomas, gingivitis, arthritic conditions such as rheumatoid arthritis and osteoarthritis, and inflammatory bowel diseases.

In another embodiment, the subject has a neoplasm. The terms "neoplasm" and "tumor" refer to a tissue growth that is characterized, in part, by angiogenesis. Neoplasms may be benign and are exemplified, but not limited to, a hemangioma, glioma, teratoma, and the like. Neoplasms may alternatively be malignant, for example, a carcinoma, sarcoma, glioblastoma, astrocytoma, neuroblastoma, retinoblastoma, and the like.

The terms "malignant neoplasm" and "malignant tumor" refer to a neoplasm that contains at least one cancer cell. A "cancer cell" refers to a cell undergoing early, intermediate or advanced stages of multi-step neoplastic progression as previously described (H.C. Pitot (1978) in "Fundamentals of Oncology," Marcel Dekker (Ed.), New York pp 15-28). The features of early, intermediate and advanced stages of neoplastic progression have been described using microscopy. Cancer cells at each of the three stages of neoplastic progression generally have abnormal karyotypes, including translocations, inversion, deletions, isochromosomes, monosomies, and extra chromosomes. A cell in the early stages of malignant progression is referred to as "hyperplastic cell" and is characterized by dividing without control and/or at a greater rate than a normal cell of the same cell type in the same tissue. Proliferation may be slow or rapid, but continues unabated. A cell in the intermediate stages of neoplastic progression is referred to as a "dysplastic cell." A dysplastic cell resembles an immature epithelial cell, is generally spatially disorganized within the tissue and loses its specialized structures and functions. During the intermediate

stages of neoplastic progression, an increasing percentage of the epithelium becomes composed of dysplastic cells. "Hyperplastic" and "dysplastic" cells are referred to as "pre-neoplastic" cells. In the advanced stages of neoplastic progression a dysplastic cell become a "neoplastic" cell. Neoplastic cells are typically invasive (*i.e.*, they either invade adjacent tissues, or are shed from the primary site and circulate through the blood and lymph) to other locations in the body where they initiate one or more secondary cancers (*i.e.*, "metastases"). Thus, the term "cancer" is used herein to refer to a malignant neoplasm, which may or may not be metastatic. Malignant neoplasms that can be diagnosed using a method of the invention include, for example, carcinomas such as lung cancer, breast cancer, prostate cancer, cervical cancer, pancreatic cancer, colon cancer, ovarian cancer; stomach cancer, esophageal cancer, mouth cancer, tongue cancer, gum cancer, skin cancer (*e.g.*, melanoma, basal cell carcinoma, Kaposi's sarcoma, *etc.*), muscle cancer, heart cancer, liver cancer, bronchial cancer, cartilage cancer, bone cancer, testis cancer, kidney cancer, endometrium cancer, uterus cancer, bladder cancer, bone marrow cancer, lymphoma cancer, spleen cancer, thymus cancer, thyroid cancer, brain cancer, neuron cancer, mesothelioma, gall bladder cancer, ocular cancer (*e.g.*, cancer of the cornea, cancer of uvea, cancer of the choroids, cancer of the macula, vitreous humor cancer, *etc.*), joint cancer (*e.g.*, synovium cancer), glioblastoma, lymphoma, and leukemia. Malignant neoplasms are further exemplified by sarcomas (such as osteosarcoma and Kaposi's sarcoma). The invention expressly contemplates within its scope any malignant neoplasm, so long as the neoplasm is characterized, at least in part, by angiogenesis associated with $\alpha4\beta1$ expression by the newly forming blood vessels.

The terms "reducing the severity of a pathological condition," "diminishing the severity of a pathological condition, and "reducing symptoms associated with a pathological condition" mean that adverse clinical signs or symptoms associated with the pathological condition are reduced, delayed, or eliminated, as compared to the level of the pathological condition in the absence of treatment with the particular composition or method. The effects of diminishing the severity of a pathological condition may be determined by methods routine to those skilled in the art including, but not limited to, angiography, ultrasonic evaluation, fluoroscopic imaging, fiber optic endoscopic examination, biopsy and histology, blood tests, which can be used to determine relevant enzyme levels or circulating antigen or antibody, imaging tests which can be used to detect a decrease in the growth rate or size of a neoplasm, or an ophthalmic procedure which can be used to identify a reduction in the number of blood vessels in the retina of a diabetic patient. Such clinical tests are selected based on the particular pathological condition being treated. For example, it is contemplated that the methods of the invention result in a "reduction in tumor tissue" (*e.g.*, a decrease in the size, weight, and/or volume of the tumor tissue) as compared to a control

tumor tissue (*e.g.*, the same tumor prior to treatment with the invention's methods, or a different tumor in a control subject). A reduction in the severity of a pathological condition also can be detected based on comments made by the patient being treated, for example, that a patient suffering from arthritis feels less pain or has greater joint mobility, or that a patient with diabetic retinopathy or with macular degeneration due to neovascularization can see more clearly, or the like.

Pathological conditions that are amenable to prevention and/or treatment with the invention's methods include any pathological condition whose development or progression in a tissue involves HPC adhesion, migration and/or differentiation. Exemplary pathological conditions include, for example, solid tumor cancers, solid tumor metastases, angiofibromas, skin cancer, retrolental fibroplasia, Kaposi's sarcoma, childhood hemangiomas, diabetic retinopathy, neovascular glaucoma, age related macular degeneration, psoriasis, gingivitis, rheumatoid arthritis, osteoarthritis, ulcerative colitis, Crohn's disease, inflammatory bowel disease, and atheroscrelotic plaques.

Other pathological conditions include those that entail injury to tissue. The term "injured" in reference to a tissue refers to tissue in which the cellular organization of the tissue has been altered as compared to the cellular organization in normal tissue. Such injury may result, for example, from a breaking of the skin tissue (*e.g.*, a cut, slash, laceration) such as accidental cuts or cuts associated with burns, surgery, *etc.* Injured tissues include lung, breast, prostate, cervical, pancreatic, colon, ovarian, stomach, esophagus cancer, mouth cancer, tongue cancer, gum, muscle, *etc.* In particular, skin injury that is associated with undesirable formation of scar tissue is particularly amenable to the invention's therapeutic approaches.

An agent that is useful in altering binding of integrin $\alpha4\beta1$ to a $\alpha4\beta1$ ligand may be administered by various routes including, for example, orally, intranasally, or parenterally, including intravenously, intramuscularly, subcutaneously, intraorbitally, intracapsularly, intrasynovially, intraperitoneally, intracisternally or by passive or facilitated absorption through the skin using, for example, a skin patch or transdermal iontophoresis. Furthermore, the agent can be administered by injection, intubation, via a suppository, orally or topically, the latter of which can be passive, for example, by direct application of an ointment or powder containing the agent, or active, for example, using a nasal spray or inhalant. The agent can also be administered as a topical spray, if desired, in which case one component of the composition is an appropriate propellant. The pharmaceutical composition also can be incorporated, if desired, into liposomes, microspheres or other polymer matrices (Gregoriadis, "Liposome Technology," Vol. 1, CRC Press, Boca Raton, FL 1984). Liposomes, for example, which consist of phospholipids or other lipids, are nontoxic, physiologically acceptable and metabolizable carriers that are relatively simple to

make and administer. Liposomes are lipid-containing vesicles having a lipid bilayer as well as other lipid carrier particles that can entrap chemical agents. Liposomes may be made of one or more phospholipids, optionally including other materials such as sterols. Suitable phospholipids include phosphatidyl cholines, phosphatidyl serines, and many others that are well known in the art. Liposomes can be unilamellar, multilamellar or have an undefined lamellar structure. For example, in an individual suffering from a metastatic carcinoma, the agent in a pharmaceutical composition can be administered intravenously, orally or by another method that distributes the agent systemically.

Agents that inhibit the specific binding of integrin $\alpha4\beta1$ to one or more of its ligands may be administered in conjunction with other therapies. For example, in the case of cancer therapy, the agent may be administered in conjunction with conventional drug therapy and/or chemotherapy that is directed against solid tumors and for control of establishment of metastases. In one embodiment, the agent is administered during or after chemotherapy. In a more preferred embodiment, the agent is administered after chemotherapy, at a time when the tumor tissue will be responding to the toxic assault. The tumor will attempt to induce angiogenesis to recover by the provision of a blood supply and nutrients to the tumor tissue. Such recovery will be thwarted by the administration of agents which inhibit angiogenesis by inhibiting the specific binding of integrin $\alpha4\beta1$ to one or more of its ligands. In an alternative embodiment, the agent may be administered after surgery in which solid tumors have been removed as a prophylaxis against future metastases.

In one embodiment, an agent is administered in a "therapeutic amount" (*i.e.,* in an amount which is sufficient to achieve a desired result). In particular, a therapeutic amount is that amount which inhibits the specific binding of $\alpha4\beta1$ integrin to its specific ligand in a tissue of a subject, and which results in the reduction, delay, or elimination of undesirable pathologic effects in the subject. One of ordinary skill recognizes that a "therapeutically effective" amount varies depending on the therapeutic agent used, the subject's age, condition, and sex, and on the extent of the disease in the subject. Generally, the dosage should not be so large as to cause adverse side effects, such as hyperviscosity syndromes, pulmonary edema, congestive heart failure, and the like. The dosage can also be adjusted by the individual physician or veterinarian to achieve the desired therapeutic goal.

A therapeutic amount may be determined using *in vitro* and *in vivo* assays known in the art, and is generally about 0.0001 to 100 mg/kg body weight.

The "subject" to whom the agents are administered includes any animal which is capable of developing angiogenesis in a tissue, including, without limitation, human and non-human animals such simians, rodents, ovines, bovines, ruminants, lagomorphs, porcines, caprines, equines, canines, felines, aves, *etc.* Preferred non-human animals are members of the Order Rodentia (*e.g.*, mouse and rat). Thus, the compounds of the invention

may be administered by human health professionals as well as veterinarians.

F. Detecting Hematopoietic Progenitor Cells That Express Integrin $\alpha4\beta1$

The invention additionally provides methods for detecting HPCs that express integrin $\alpha4\beta1$ by using an agent that specifically binds to integrin $\alpha4\beta1$ polypeptides and/or to integrin $\alpha4\beta1$ mRNA. These methods are useful for identifying the presence of HPCs whose adhesion, migration, and differentiation is amenable to modulation using the invention's methods, regardless of whether such HPCs are located in normal tissue or in tissue involved in a pathological condition. As such, the invention further provides methods of diagnosing a pathological condition characterized by involvement of HPCs that express integrin $\alpha4\beta1$.

Integrin $\alpha4\beta1$ polypeptide may be detected using Western blot analysis or immunofluorescence. Alternatively, the presence of integrin $\alpha4\beta1$ mRNA using reverse transcription polymerase chain (RT-PCR), or *in situ* hybridization.

In one embodiment, the agent which is used in detecting the presence of integrin $\alpha4\beta1$ polypeptide and/or mRNA can be detectably labeled, for example, by linking the agent to a moiety, which is selected based, for example, on whether specific binding of the agent is to be detected *in vivo* or whether a tissue to which the agent is suspected of binding is to be removed (*e.g.*, by biopsy) and examined *ex vivo*.

A moiety useful for labeling an agent antagonist can be a radionuclide, a paramagnetic material, an X-ray attenuating material, a fluorescent, chemiluminescent or luminescent molecule, a molecule such as biotin, or a molecule that can be visualized upon reaction with a particular reagent, for example, a substrate for an enzyme or an epitope for an antibody. The moiety can be linked to an agent using well known methods, which are selected, in part, based on the chemical nature of the agent and the moiety. For example, where the moiety is an amino acid sequence such as a hexahistidine (His6) sequence, and the agent is a peptide, the His6 sequence can be synthesized as part of the peptide, and the His6-labeled agent can be identified by the binding of a nickel ion reagent to the His6 moiety.

Methods for chemically linking a moiety to an agent also can be utilized. For example, methods for conjugating polysaccharides to peptides are exemplified by, but not limited to coupling via alpha- or epsilon-amino groups to $NaIO_4$-activated oligosaccharide, using squaric acid diester (1,2-diethoxycyclobutene-3,4-dione) as a coupling reagent, coupling via a peptide linker wherein the polysaccharide has a reducing terminal and is free of carboxyl groups (U.S. Patent No. 5,342,770), coupling with a synthetic peptide carrier derived from human heat shock protein hsp65 (U.S. Patent No. 5,736,146), and using the methods of U.S. Patent No. 4,639,512. Methods for conjugating proteins to proteins include

coupling with a synthetic peptide carrier derived from human heat shock protein hsp65 (U.S. Patent No. 5,736,146), the methods used to conjugate peptides to antibodies (U.S. Patent Nos. 5,194,254; 4,950,480), the methods used to conjugate peptides to insulin fragments (U.S. Patent No. 5,442,043), the methods of U.S. Patent No. 4,639,512, and the method of conjugating the cyclic decapeptide polymyxin B antibiotic to and IgG carrier using EDAC (1-ethyl-3-(3-dimethylaminopropyl)carbodiimide)-mediated amide formation (Drabick *et al.* (1998) Antimicrob. Agents Chemother. 42:583-588). Approaches to conjugate nucleic acids to proteins are also known in the art, such as those described in U.S. Patent Nos. 5,574,142; 6,117,631; 6,110,687; each of is incorporated in its entirety by reference. Methods for conjugating lipids to peptides have been described in the art including, but not limited to, the use of reductive amination and an ether linkage which contains a secondary or tertiary amine (U.S. Patent No. 6,071,532), the methods of U.S. Patent No. 4,639,512, the methods used for covalently coupling peptides to unilamellar liposomes (Friede *et al.* (1994) Vaccine 12:791-797), of coupling human serum albumin to liposomes using the hetero-bifunctional reagent N-succinimidyl-S-acetylthioacetate (SATA) (Kamps *et al.* (1996) Biochim. Biophys. Acta 1278:183-190), of coupling antibody Fab' fragments to liposomes using a phospholipid-poly(ethylene glycol)-maleimide anchor (Shahinian *et al.* (1995) Biochim. Biophys. Acta 1239:157-167), and of coupling *Plasmodium* CTL epitope to palmitic acid via cysteine-serine spacer amino acids (Verheul *et al.* (1995) J. Immunol. Methods 182:219-226).

A specifically bound agent can be detected in an individual using an *in vivo* imaging method, such as a radionuclide imaging, positron emission tomography, computerized axial tomography, X-ray or magnetic resonance imaging method, or can be detected using an *ex vivo* method, wherein, following administration, a sample of the tissue is obtained from the individual, and specific binding of the agent in the sample is detected (*e.g.*, by immunohistochemical analysis; see WO 03/019136 A3 to Varner).

An agent that is specifically bound to $\alpha4\beta1$ integrin in a sample can be detected directly by detecting the agent, or indirectly by detecting the presence of a moiety such as by detecting radioactivity emitted by a radionuclide moiety. Specifically bound agent also can be detected indirectly by further contacting it with a reagent that specifically interacts with the agent, or with a moiety linked to the agent, and detecting interaction of the reagent with the agent or label. For example, the moiety can be detected by contacting it with an antibody that specifically binds the moiety, particularly when the moiety is linked to the agent. The moiety also can be, for example, a substrate, which is contacted by an enzyme that interacts with and changes the moiety such that its presence can be detected. Such indirect detection systems, which include the use of enzymes such as alkaline phosphatase, horseradish peroxidase, beta-galactosidase and the like, are well known in the art and

commercially available, as are the methods for incorporating or, linking the particular moiety to a particular type of agent.

G. Screening Compounds

The invention also provides methods for screening test compounds for altering the level of hematopoietic cell adhesion and/or migration to a target tissue, and for altering hematopoietic progenitor cell differentiation into a second cell type, comprising: a) providing: i) a first composition comprising integrin α4β1, ii) a second composition comprising one or more integrin α4β1 ligand, iii) a test compound, b) contacting said test compound with one or more of said first composition and said second composition under conditions for specific binding of said integrin α4β1with said integrin α4β1 ligand, and c) detecting an altered level of specific binding of said integrin α4β1with said integrin α4β1 ligand in the presence of said test compound compared to in the absence of said test compound, thereby identifying said test compound as altering the level of hematopoietic cell adhesion and/or migration to a target tissue, and as altering hematopoietic progenitor cell differentiation into a second cell type.

The tissue can be contacted with the agent *in vivo* or *ex vivo* (see, for example, U.S. Patent No. 5,622,699, incorporated by reference). Where a screening method of the invention is performed using an *in vitro* format, it can be adapted to automated procedure, thus allowing high throughput screening assays for examining libraries of molecules to identify potential α4β1 antagonists, which can alter HPC adhesion, migration, and/or differentiation.

Alternatively, a screening assays is carried out by contacting isolated HPCs with a test compound, and detecting an altered level of HPC adhesion, migration and/or differentiation, thereby identifying the compound as altering the level of HPC adhesion, migration and/or differentiation.

Test compounds may be made by art-known methods for preparing libraries of molecules, and are exemplified by methods for preparing oligonucleotide libraries (Gold *et al.*, U.S. Patent No. 5,270,163, incorporated by reference); peptide libraries (Koivunen *et al.*, supra, 1993, 1994); peptidomimetic libraries (Blondelle *et al.*, Trends Anal. Chem. 14:83-92 (1995)) oligosaccharide libraries (York *et al.*, Carb. Res. 285:99-128 (1996) ; Liang *et al.*, Science 274:1520-1522 (1996); and Ding *et al.*, Adv. Expt. Med. Biol. 376:261-269 (1995)); lipoprotein libraries (de Kruif *et al.*, FEBS Lett., 399:232-236 (1996)); glycoprotein or glycolipid libraries (Karaoglu *et al.*, J. Cell Biol. 130:567-577 (1995)); or chemical libraries containing, for example, drugs or other pharmaceutical agents (Gordon *et al.*, J. Med. Chem. 37:1385-1401 (1994); Ecker and Crook, Bio/Technology 13:351-360 (1995), U.S. Patent No. 5,760,029, incorporated by reference). Libraries of

diverse molecules also can be obtained from commercial sources.

H. Isolating Hematopoietic Progenitor Cells

The invention further provides a method for isolating HPCs from a tissue by treating a tissue which contains HPCs with an agent (e.g. antibody) capable of specific binding to integrin $\alpha4\beta1$, and isolating HPCs to which the agent binds. These methods are based, in part, on the inventor's discovery that HPCs express integrin $\alpha4\beta1$.

In one embodiment, HPCs comprise endothelial progenitor cells (EPCs). EPCs useful in regulating angiogenesis (Isner *et al.*, U.S. Patent No. 5,980,887, incorporated by reference). Heterologous, homologous, and autologous endothelial cell progenitor grafts incorporate *in vivo* into sites of active angiogenesis or blood vessel injury (*i.e.*, they selectively migrate to such locations (Isner *et al.*, U.S. Patent No. 5,980,887). Endothelial cell progenitors are present in a number of tissues including, for example, peripheral blood, bone marrow, and umbilical cord blood. Endothelial cell progenitors may be isolated in accordance with the invention's methods by treating a tissue (*e.g.*, peripheral blood, bone marrow, umbilical cord blood, *etc.*) which contains endothelial cell progenitors with an antibody which is capable of specific binding to at least a portion of integrin $\alpha4\beta1$ polypeptide, followed by isolating cells which bind to the antibody. The endothelial cell progenitor nature of the isolated cells may be confirmed by determining the presence of endothelial cell progenitor-specific antigens (*e.g.*, CD34, flk-1, and/or tie-2) on the surface of the isolated cells using commercially available antibodies to these antigens. It may be desirable, but not necessary, to expand endothelial cell progenitors *in vivo* prior to treating the tissue that contains endothelial cell progenitors by administration of recruitment growth factors (*e.g.*, GM-CSF and IL-3) to the patient.

Thus, in one embodiment, the isolated endothelial cell progenitors can be used to enhance angiogenesis or to deliver an angiogenesis modulator (*e.g.*, anti- or pro-angiogenic agents, respectively), to sites of pathologic or utilitarian angiogenesis. Additionally, in another embodiment, endothelial cell progenitors can be used to induce re-endothelialization of an injured blood vessel, and thus reduce restenosis by indirectly inhibiting smooth muscle cell proliferation (Isner *et al.*, U.S. Patent No. 5,980,887).

In one preferred embodiment, the endothelial cell progenitors can be used alone to potentiate a patient for angiogenesis. Some patient populations, typically elderly patients, may have either a limited number of endothelial cells or a limited number of functional endothelial cells. Thus, if one desires to promote angiogenesis, for example, to stimulate vascularization by using a potent angiogenesis such as VEGF, such vascularization can be limited by the lack of endothelial cells. However, by administering the endothelial cell progenitors one can potentiate the vascularization in those patients.

Because endothelial cell progenitors home to foci of angiogenesis, these cells are also useful as autologous vectors for gene therapy and diagnosis of ischemia or vascular injury. For example, these cells can be utilized to inhibit as well as augment angiogenesis. For anti-neoplastic therapies, for example, endothelial cell progenitors can be transfected with or coupled to cytotoxic agents, cytokines or co-stimulatory molecules to stimulate an immune reaction, other anti-tumor drugs, or angiogenesis inhibitors. For treatment of regional ischemia, angiogenesis could be amplified by prior transfection of endothelial cell progenitors to achieve constitutive expression of angiogenic cytokines and/or selected matrix proteins. In addition, the endothelial cell progenitors may be labeled (*e.g.*, radiolabeled), administered to a patient and used in the detection of ischemic tissue or vascular injury.

Autologous endothelial cell progenitor transplants have been successfully used, and endothelial cell progenitors have been shown to be easily manipulated and expanded *ex vivo* (U.S. Patent Nos. 5,980,887; 5,199,942; and 5,541,103, the disclosures of which are incorporated by reference).

Once isolated, HPCs (such as endothelial progenitor cells) may optionally stored in cryogenic conditions before administering to a subject to treat a number of conditions. Administration to a subject may be by any suitable means, including, for example, intravenous infusion, bolus injection, and site directed delivery via a catheter. Preferably, the HPCs obtained from the subject are re-administered. Generally, from about 10^6 to about 10^{18} HPCs are administered to the subject for transplantation.

In one embodiment, HPCs (such as endothelial progenitor cells) may be transgenic or wild type. A "transgenic" cell refers to a cell which contains a "transgene," *i.e.*, any nucleic acid sequence which is introduced into the cell by experimental manipulations. A transgene may be an "endogenous DNA sequence" or a "heterologous DNA sequence" (*i.e.*, "foreign DNA"). A transgenic cell is contrasted with a "wild-type cell" that does not contain a transgene. HPCs may be transgenic for genes that encode a variety of proteins including anticancer agents, as exemplified by genes encoding various hormones, growth factors, enzymes, cytokines, receptors, MHC molecules and the like. The term "genes" includes nucleic acid sequences both exogenous and endogenous to cells into which a virus vector, for example, a pox virus such as swine pox containing the human TNF gene may be introduced. Additionally, it is of interest to use genes encoding polypeptides for secretion from the HPCs so as to provide for a systemic effect by the protein encoded by the gene. Specific genes of interest include those encoding TNF, TGF-α, TGF-β, hemoglobin, interleukin-1, interleukin-2, interleukin-3, interleukin-4, interleukin-5, interleukin-6, interleukin-7, interleukin-8, interleukin-9, interleukin-10, interleukin-11, interleukin-12 *etc.*, GM-CSF, G-CSF, M-CSF, human growth factor, co-stimulatory factor B7, insulin, factor

VIII, factor IX, PDGF, EGF, NGF, EPO, β-globin, cell mitogens and the like, as well as biologically active modifications of these proteins. The gene may further encode a product that regulates expression of another gene product or blocks one or more steps in a biological pathway. In addition, the gene may encode a toxin fused to a polypeptide (*e.g.*, a receptor ligand), or an antibody that directs the toxin to a target, such as a tumor cell. Similarly, the gene may encode a therapeutic protein fused to a targeting polypeptide, to deliver a therapeutic effect to a diseased tissue or organ.

In another embodiment, HPCs (such as endothelial progenitor cells) can also be used to deliver genes to enhance the ability of the immune system to fight a particular disease or tumor. For example, the cells can be used to deliver one or more cytokines (*e.g.*, IL-2) to boost the immune system and/or one or more antigens.

In yet another embodiment, HPCs (such as endothelial progenitor cells) may also be used to selectively administer drugs, such as an antiangiogenesis compound such as O-chloroacetyl carbamoyl fumagillol (TNP-470). Preferably, the drug would be incorporated into the cell in a vehicle such as a liposome, a timed released capsule, *etc.* The HPCs (such as endothelial progenitor cells) would then selectively target a site of active angiogenesis such as a rapidly growing tumor where the compound would be released. By this method, one can reduce undesired side effects at other locations.

In a further embodiment, HPCs (such as endothelial progenitor cells) may be used to enhance blood vessel formation in ischemic tissue (*i.e.*, a tissue having a deficiency in blood as the result of an ischemic disease). Such tissues can include, for example, muscle, brain, kidney and lung. Ischemic diseases include, for example, cerebrovascular ischemia, renal ischemia, pulmonary ischemia, limb ischemia, ischemic cardiomyopathy and myocardial ischemia. Methods for inducing the formation of new blood vessels in ischemic tissue are disclosed in Isner *et al.*, U.S. Patent No. 5,980,887, herein incorporated by reference.

EXPERIMENTAL

The following examples serve to illustrate certain preferred embodiments and aspects of the present invention and are not to be construed as limiting the scope thereof.

EXAMPLE 1

Inhibition of Endothelial Progenitor Cell Migration *In Vivo* in Mouse and Rat Animal Models

Integrin α4β1 inhibitors can be used to prevent endothelial cell precursors from exiting the blood stream and entering sites of neovascularization. Angiogenesis assay are performed in mouse or nude rats transplanted with murine Tie2-LacZ bone marrow by injecting matrigel, a viscous extracellular matrix that solidifies at body temperature,

containing angiogenic growth factors. Mice are treated by intravenous injection with anti-murine α4β1 and control antibodies or other inhibitors of α4β1. α4β1 inhibitors are anticipated to block LacZ staining cells from incorporating into blood vessels, indicating that α4β1 regulates endothelial precursor cell egress from the circulation. Frozen sections of the matrigel are stained with antibodies directed CD31 and Factor VIII related antigen to obtain an indication of angiogenic index.

EXAMPLE 2

Endothelial Progenitor Cells (EPC) Express Integrin α4β1

Purified human umbilical vein endothelial cells ("HUVECS") (Clonetics, San Diego, CA) and endothelial progenitor cells ("EPCs") cultured on fibronectin from circulating CD34+ stem cells (*see* Asahara *et al.*, Science, 275:964-967, (1997)), were incubated with mouse anti-human integrin α4β1 antibodies for 60 minutes on ice, washed twice with PBS and then incubated for 30 minutes on ice in rhodamine-labeled goat anti-mouse IgG. Cells were washed twice with cold PBS then analyzed on a FACSCAN analyzer for expression of integrin α4β1. The percent cells expressing this integrin was determined and plotted according to cell type (Figure 13).

Thirty-three percent of endothelial progenitor cells were positive for integrin α4β1 expression while only 12% of HUVECS were positive. These results showed that the inhibitory effect of α4β1 antagonists in angiogenesis result from an inhibition of the participation of endothelial progenitor cells in angiogenesis.

EXAMPLE 3

α4β1 Antagonists Block Endothelial Stem Cell Contribution to Angiogenesis

Murine angiogenesis was induced by subcutaneous injection 400 µl of growth factor depleted matrigel containing 400 ng/ml bFGF or VEGF into the rear dorsal flanks of inbred mice of the strain FVB/N or into FVB/N mice that had been irradiated and transplanted with bone marrow from Tie2LacZ mice. Animals were treated by intravenous injection on day 0 and day 3 with 200 µg of endotoxin free rat anti-murine α4β1 antibody (PS-2) in 100 µl or control isotype matched rat anti-murine integrin beta 2 antibody on days 1 and 4 (n=10). After 5 days, matrigel plugs were excised, embedded in OCT, frozen and sectioned. Thin sections (5 µm) were immunostained with rat anti-murine CD31 followed by Alexa 565-conjugated goat anti-rat immunoglobulin. CD31 positive vessel density per 200X microscopic field was determined in 5 fields per matrigel plug. Mean vessel density per field +/- SEM was graphed versus treatment condition. Photographs were taken of representative fields of control IgG and anti-α4β1 treated bFGF or VEGF containing plugs stained for beta galactosidase expression, with red indicating CD31 positive blood vessels and blue

representing nuclei of all cells (Figure 14B). Sections from Tie2/LacZ transplanted mice were analyzed for presence of bone marrow derived endothelial cells by staining sections for expression of beta galactosidase using a kit from Life Technologies. Blue cells in the plugs that arose from the transplanted bone marrow were counted (Figure 14A) with bFGF stimulating angiogenesis.

Antagonists of integrin $\alpha4\beta1$ prevent the participation of endothelial progenitor cells in angiogenesis. Beta galactosidase expressing endothelial cells derive from bone marrow because these mice were irradiated to kill their own bone marrow prior to transplantation with bone marrow from mice that express LacZ under an endothelial specific promoter, the Tie2 promoter. Thus, endothelial cells that arise from bone marrow will turn blue in tissues incubated in a substrate for beta galactosidase. These data showed that fewer blue endothelial cells were induced by growth factors in mice treated with anti-$\alpha4\beta1$ than in mice treated with control antibodies. Therefore, anti-$\alpha4\beta1$ inhibited the participation in angiogenesis of endothelial progenitors derived from bone marrow.

EXAMPLE 4

Exemplary Material and Methods

The following are some exemplary materials and methods that may be useful in the invention, particularly in Examples 5-13 and Figures 15-20.

A. Chick chorioallantoic membrane angiogenesis assays

Chick chorioallantoic membranes of 10 day old chicken embryos were stimulated with 1 μg/ml bFGF and function-blocking antibodies (25 μg/ml) directed against the RGD containing cell-binding domain (CBP) and the EILDV containing C-terminal CS-1 domain of fibronectin, as well as isotype matched control antibodies (anti-MHC) were applied. Three days later, blood vessel branchpoints were counted using 30X magnification. Angiogenesis was stimulated in CAMs with 1 μg/ml bFGF, VEGF, TNFα, or IL-8. Saline or antibodies directed against integrin $\alpha4\beta1$ (mouse anti-human $\alpha4\beta1$ antibodies HP1/2, P4G9, P1H4 and rat anti-mouse $\alpha4\beta1$ PS2 were all tested were similar results) and control isotype matched antibodies were applied to CAMs and blood vessel branchpoints were counted 3 days later. Cryosections from bFGF stimulated, saline or antibody-treated CAMs were immunostained to detect blood vessel expression of von Willebrand Factor. VWF+ structures were quantified in five 200X microscopic fields. Each experiment was repeated 3-4 times and results from representative experiments are shown.

B. Murine angiogenesis assays

Angiogenesis was initiated in FVB/N mice by subcutaneous injection of 400μl growth

factor reduced matrigel supplemented with 400 ng/ml of bFGF or VEGF. Mice were treated on day 0 and 3 by intravenous injection of 200 μg function blocking rat anti-integrin α4β1 (PS/2) or isotype-matched control antibodies (rat anti-integrin β2, BD Pharmingen). Matrigel plugs were excised after 5 days and cryopreserved. Cryosections were immunostained to detect CD31 expression and counterstain with DAPI. Microvessel density was quantified in 10 randomly selected 200X microscopic fields for each plug in each treatment group (n=8). Alternatively, angiogenesis was initiated in FVB/N mice by corneal transplantation of polymerized pellets containing 400 ng/ml of VEGF. Animals (n=5) were treated on day 0 and day 3 with anti-α4β1 (PS/2) or control IgG. Fifteen minutes prior to sacrifice on day 5, mice were injected intravenously with endothelial specific lectin, Bandeira simplifolia-FITC and tissues were cryopreserved. Angiogenic response to VEGF was quantified as the percent green fluorescent area visible at 100X magnification. Additionally, five million HT29 human α4β1 negative colon carcinoma cells were implanted subcutaneously in nude mice. When tumors were palpable (about 30 mm^3), mice were treated twice weekly by i.v. injection of saline, rat-anti-mouse α4β1 or isotype matched control antibody, anti-CD11b integrin (M1/70, BD Pharmingen). Tumor dimensions were determined every other day and tumor mass was determined after four weeks of treatment. Mean tumor mass +/- SEM is presented. Cryosections of tumors were immunostained to detect CD31 (BD Pharmingen) and microvessel density was quantified for 5 randomly selected microscopic fields. Additionally, tumors were stained with hematoxylin and eosin (n=10). Three experiments were performed and selected representative data is shown. Statistical significance was determined using Student's t-test.

C. FACs analysis

The expression profile of surface antigens of human microvascular endothelial cells, human umbilical vein endothelial cells and endothelial progenitor cells was analyzed by FACs analysis using mouse antibodies directed against human α4β1 (HP1/2), αvβ3 (LM609), αvβ5 (P1F6), α5β1 (JBS5), beta 1 (P4C10), beta 7 (FIB504, Beckton Dickinson Pharmingen) CD34 (8G12, Becton Dickinson), AC133 (AC133, Miltenyi Biotec), Flk-1 (A-3, Santa Cruz Biotechnology), CD45 (2D1, Beckton Dickinson) CD31 (HEC7, Endogen), VE-Cadherin (BV6, Chemicon International), and VCAM (P8B1, Chemicon International) and rabbit anti-VWF (Dako).

D. Isolation of endothelial progenitor cells

Mononuclear cells from from human peripheral blood were isolated using known methods. In some experiments, CD34 positive cells were purified from the mononuclear population using MACS magnetic bead systems. Cells were cultured up to 9 days in

endothelial growth medium (EGM-2 containing 2% fetal bovine serum, bFGF, VEGF and). After 7 days, 80% of the cells are spindle shaped and express vascular cell markers as well as stem cell markers.

E. Adhesion and migration assays

Adhesion were performed essentially as described. For adhesion analysis, day 7 EPCs were allowed to adhere to triplicate well of 48 well plates coated with 5 μg/ml CS-1 fibronectin (recombinant H120 fragment, a kind gift from Martin J. Humphries), recombinant soluble VCAM, plasma fibronectin, vitronectin (purified as described) or collagen for 30 minutes. Plates were washed 5 times and adherent cells were quantified at 200X magnification. Alternatively, cells were stained with crystal violet, washed, air dried and extracted with acetic acid. Absorbance at 600 nm was then determined. In some experiments, 25 μg/ml function-blocking antibodies against integrins $\alpha4\beta1$ (HP1/2), $\alpha5\beta1$ (JBS5) beta 1 (P4C10), $\alpha v\beta5$ (P1F6), or $\alpha v\beta3$ (LM609) were added to the adhesion assay. Migration assays were performed as described. EPCs were added to triplicate 8μm pore size transwell inserts coated with 5 μg/ml CS-1 fibronectin (recombinant H120 fragment from Martin J. Humphries), collagen, fibronectin or vitronectin. After 4 hours, cells were fixed with 3.7% paraformaldehyde, stained with crystal violet and cells on the underside of the transwell were quantified.

F. Bone marrow transplantation

Bone marrow from Tie2LacZ transgenic mice (n=8) was transplanted into irradiated FVB/N mice. After one month of recovery, angiogenesis was initiated by injection of growth factor reduced matrigel supplemented with 400 ng/ml of bFGF or VEGF. Mice were treated on day 0 and day 3 by i.v. injection of 200 μg rat anti-mouse $\alpha4\beta1$ antibody (PS/2) or isotype matched control (anti-b2 integrin). Plugs were excised after 5-7 days and cryopreserved. Cryosections were treated to detect expression of beta galactosidase within the matrigel plugs. Micrographs were taken at 200X and at 600X magnification. Lac Z positive cells per 200X field were quantified in 10 microscopic fields. Cryosections were also immunostained with rabbit anti-beta galactosidase and rat anti-murine CD31. Micrographs are taken at 200X. LacZ, CD31 positive vessels were quantified in 10 microscopic fields. Statistical significance was determined using Student's t-test.

EXAMPLE 5

In studies to analyze the roles of fibronectin and its receptors in angiogenesis, we found that antagonists of the RGD cell-binding domain of fibronectin and its receptor $\alpha5\beta1$ potently block angiogenesis (Kim *et al.*, Am J Pathol. 2000 Apr;156(4):1345-62). To our

surprise, antibodies that recognize the EILDV site in the alternatively spliced domain of tissue fibronectin, CS-1 fibronectin, potently blocked angiogenesis in the chick chorioallantoic membrane (CAM) model (Figure 15A, $P < 0.05$). These antagonists interfere with the binding of CS-1 fibronectin to its principle receptor, integrin $\alpha4\beta1$(Guan *et al.*, Cell. 1990 Jan 12;60(1):53-61). Importantly, these antibodies inhibited the attachment and migration of cultured human endothelial cells on CS-1 fibronectin. These results suggest that CS-1 fibronectin and its receptor integrin $\alpha4\beta1$ may play roles in angiogenesis. These findings are consistent with our previous observation that fibronectin expression is significantly upregulated during angiogenesis (Kim *et al.* 2000 supra) and the independent reports showing that CS-1 fibronectin expression is upregulated in association with vessels during wound repair in skin, heart and other tissues, as well as during chronic inflammatory diseases such as rheumatoid arthritis (Elices *et al.*, J Clin Invest. 1994 93(1):405-16; Morales-Ducret *et al.*, J Immunol. 1992 149(4):1424-31). Based on these results, we considered whether $\alpha4\beta1$ was involved in angiogenesis. To evaluate the role of $\alpha4\beta1$ in angiogenesis, $\alpha4\beta1$ function-blocking antibodies were applied to CAMs stimulated with bFGF, VEGF, TNFα or IL-8. Anti-$\alpha4\beta1$ blocked angiogenesis induced by each of these growth factors (Figure 15B, $P< 0.05$). These studies indicate that integrin $\alpha4\beta1$ plays a role in neovascularization in the chick CAM model.

EXAMPLE 6

To assess the role of $\alpha4\beta1$ in mammalian angiogenesis, we tested the effects of antagonists of integrin $\alpha4\beta1$ in several murine models of neovascularization. We injected anti-integrin $\alpha4\beta1$ antibody (PS/2) intravenously into mice that were stimulated to undergo angiogenesis by subcutaneous injection of either bFGF or VEGF saturated Matrigel. (Figure 15C). We found that inhibition of $\alpha4\beta1$ significantly blocked angiogenesis, whether assessed by microvascular density or total vessel content ($P< 0.05$). Additionally, peptide antagonists of $\alpha4\beta1$ (EILDV, derived from CS-1 fibronectin) also blocked neovascularization in this model, providing further support for a role of for $\alpha4\beta1$ in this process. Anti-$\alpha4\beta1$ antibodies also blocked corneal angiogenesis ($P< 0.05$). Importantly, antagonists of integrin$\alpha4\beta1$ significantly inhibited tumor angiogenesis and tumor growth (Figure 15D-E). Thus, CS-1 fibronectin and its receptor integrin $\alpha4\beta1$ play important roles in the control of neovascularization.

EXAMPLE 7

We next reasoned that if $\alpha4\beta1$ regulates angiogenesis, this integrin should be expressed on the vasculature of tumors and other neovascular tissues. To evaluate the expression pattern of integrin $\alpha4\beta1$ on the neovascular beds of human tumors, we performed

immunohistochemistry to detect expression of integrin $\alpha4\beta1$ and von Willebrand Factor, a marker of vascular endothelium (Kim *et al.* 2000 supra). Using a variety of monoclonal anti-$\alpha4$ antibodies, to our surprise we were rarely able to show expression of $\alpha4$ on tumor endothelium, yet we detected integrin $\alpha4$ expression in control tissues such as lymph node and human melanoma (refs; Figure 16A). Occasionally, we detected $\alpha4\beta1$ expression on a subset of blood vessels within tumors, such as invasive ductal breast carcinoma (Figure 16A). Using an antibody that reacts with the cytoplasmic tail of alpha 4, we were able to detect high levels of alpha 4 expression on vascular endothelial cells in growth factor stimulated CAMs, growth factor stimulated murine tissue, murine tumors and human tumors (Figure 16B). However, unlike neovascular integrins $\alpha5\beta1$ and $\alpha v\beta3$ (Brooks *et al.*, Science. 1994 264:569-71), integrin $\alpha4\beta1$ is only weakly expressed on proliferating human microvascular or venous endothelial cells *in vitro* (Figure 16C).

EXAMPLE 8

As $\alpha4\beta1$ is only weakly expressed on proliferating purified endothelial cells, we reasoned that this integrin might be transiently expressed by endothelial cells *in vivo* or expressed by endothelial precursors during neovascularization. Since new vessels can arise not only by sprouting but also by the seeding of bone marrow derived stem cells in tissues, we considered whether EPCs may express $\alpha4\beta1$. To isolate EPCs, we cultured the mononuclear fraction of peripheral blood leukocytes or CD34 positive stem cells (isolated from the mononuclear fraction of peripheral blood leukocytes) on fibronectin cultured plates in the presence of the angiogenic cytokines bFGF and VEGF. The resulting EPCs not only express high levels of $\alpha4\beta1$ but also co-express stem cell markers such as CD34, CD133, Flk-1 (Asahara et al., *et al.*, 1997 Feb supra; Brooks *et al.*, Science. 1994 supra), CD45 and CD18 as well as endothelial markers such as VE-cadherin, VCAM, CD31 and VWF (Figure 16D-E). With increasing time in culture, these cells acquire additional characteristics of endothelial cells, expressing increasing amounts of CD34, VE-cadherin, VCAM, and VWF (Figure 16D-E). These cells exhibit a larger, elongated, adherent morphology and spontaneously form tube-like structures (Figure 16F). Importantly, while EPCs are strongly positive for integrin $\alpha4\beta1$, they fail to express the closely related leukocyte integrin $\alpha4\beta7$ (Figure 16D). EPCs are also positive for other adhesion receptors, including integrin $\alpha5\beta1$, the RGD-binding fibronectin receptor (Kim *et al.* 2000 supra). Strikingly, EPCs express little integrin $\alpha v\beta5$ and no $\alpha v\beta3$ during their early stages of in vitro development but high levels of these integrins are observed in later stages (Figure 16E), suggesting that these integrins are upregulated as EPCs acquire increasingly greater endothelial characteristics. The EPCs are also positive for UEA lectin staining, a characteristic of cells of endothelial lineage and bind DiI acetylated LDL. Thus, in contrast to mature endothelial cells, EPCs are strongly positive

for integrin α4β1 expression.

EXAMPLE 9

Since integrins on circulating lymphocytes are often maintained in an inactive or low affinity state (Peichev *et al.*, Blood. 2000 Feb 1;95(3):952-8), we next determined whether the integrin α4β1 expressed by EPCs is functional. In fact, EPCs attach to and migrate on CS-1 fibronectin, as well as collagen, plasma fibronectin, and vitronectin. Importantly, adhesion to CS-1 fibronectin is mediated by integrin α4β1, as function-blocking anti-α4β1 and β1 antibodies prevented EPC attachment to this matrix protein (Figure 17A). Since α4β1 is also a receptor for the immunoglobulin superfamily molecule VCAM that is expressed by activated endothelium, we also examined the ability of EPCs to attach to plates coated with recombinant soluble VCAM (rsVCAM). Antagonists of α4β1 blocked EPC attachment to VCAM, indicating that integrin α4β1 is a functionally active receptor for both CS-1 fibronectin and VCAM on endothelial stem cells (Figure 17B).

EXAMPLE 10

To determine whether EPCs can attach to proliferating vascular endothelium that has been stimulated by angiogenic growth factors, we plated EPCs labeled with DiI-acetylated LDL onto proliferating endothelial monolayers. EPCs bound strongly to endothelium in a α4β1 dependent manner (Figure 17C) and that rsVCAM blocked EPC attachment to endothelial monolayers (Figure 17D). Similar results were obtained when α4β1 antibodies or rsVCAM were pre-incubated with EPCs, but not when they were pre-incubated with endothelial monolayers. Thus, α4β1 mediates the attachment of EPCs to VCAM on vascular endothelium. As VCAM is upregulated in endothelium undergoing angiogenesis in response to inflammatory cytokines and growth factors and recombinant soluble forms of VCAM can inhibit angiogenesis (Nakao *et al.* J. Immunol. 2003 Un 1;170(11):5704-11), these results suggest that α4-VCAM interactions may facilitate the movement of bone marrow derived stem or precursor cells into tissues during angiogenesis and tissue repair. In fact, integrin α4β1-VCAM interactions play obligatory roles in facilitating heterotypic cell adhesion *in vivo* during embryonic development, (chorion-allantois, endocardium-myocardium, primary myoblast fushions), in immune cell trafficking (extravasation of lymphocytes, monocytes, and eosinophils in inflammation) and in retention of immune cell precursors in the bone marrow (Rosen *et al.*, Cell. 1992 Jun 26;69(7):1107-19). Thus α4-VCAM interactions may regulate stem cell entry into sites of tissues repair.

EXAMPLE 11

To determine whether α4β1 regulates the formation of neovessels by EPCs, we

subcutaneously implanted nude mice with DiI labeled human EPCs in matrigel containing VEGF and anti-human α4β1 or control antibodies. After five days, neovessels were visualized with an injection of Bandeira simplifolia. We observed that many EPCs formed vessels (Figure 18A) and that anti-α4β1 but not control antibodies blocked vessels formation. These studies indicate that EPCs are competent to form neovessels and that α4β1 function is required for this process.

EXAMPLE 12

To determine whether α4β1 mediates the attachment of EPCs to angiogenic endothelium *in vivo*, we adoptively transferred human EPCs into nude mice bearing subcutaneously implanted integrin α4β1 negative colon carcinoma tumors. Mice were systemically treated with anti-human α4β1 antibodies, control antibodies or saline. We found that EPCs incorporated into neovessels and that only antagonists of human α4β1 blocked this event (Figure 18B). These finding demonstrate that integrin α4β1 mediates the extravasation of endothelial stem cells from the circulation into angiogenic tissue. As all CD34 positive stem cells must cross the endothelium to enter into tissues, these studies suggest that α4β1 mediates stem cell trafficking *in vivo*.

EXAMPLE 13

To investigate the role of α4β1 in the regulation of bone marrow derived endothelial stem cell trafficking *in vivo*, we induced angiogenesis in mice transplanted with bone marrow from Tie2Lac Z mice and systemically treated the animals with anti-murine α4β1 antibodies (PS/2) and control antibodies (anti-murine β2 integrin). We determined that anti-α4β1 antibodies, but not anti-β2 antibodies, significantly blocked the incorporation of LacZ positive cells and vessels in matrigel whether angiogenesis was induced by bFGF or by VEGF (Figure 18C-D). To further determine whether Lac Z positive cells incorporate into blood vessels and express endothelial markers, we immunostained cryosections with anti-beta-galactosidase (green) and anti-murine CD31 (red). We identified a significant number of the Lac Z positive bone marrow derived cells (>90%) within CD31 positive vessels and observed that antagonists of α4β1 blocked the incorporation of these cells into neovessels (Figure 18E-F). These studies indicate that α4β1 promotes the entry of bone marrow derived endothelial stem cells into tissues where they participate in the formation of neovasculature.

EXAMPLE 14

Additional data herein is shown in Figure 19. Figure 19A shows migration of endothelial cells on 8 μm pore transwells coated with 5 μg/ml CS-1 fibronectin in the

presence of medium, anti-CS-1 fibronectin or control antibodies (W6/32, anti-MHC). Figure 19B, C shows adhesion of endothelial cells to plastic plates coated with 5 μg/ml CS-1 fibronectin, in the presence of medium, anti-α4β1 (HP1/2) or control antibodies (P1F6). Figure 19D shows cryosections from bFGF stimulated, saline or antibody-treated CAMs were immunostained to detect blood vessel expression of von Willebrand Factor. VWF+ structures were quantified in five 200X microscopic fields. Figure 19E shows angiogenesis was initiated in FVB/N mice by corneal transplantation of polymerized pellets containing 400 ng/ml of VEGF. Animals (n=5) were treated on day 0 and day 3 with anti-α4β1 (PS/2) or control IgG (cIgG). Fifteen minutes prior to sacrifice on day 5, mice were injected intravenously with endothelial specific lectin, Bandeira simplifolia-FITC and tissues were cryopreserved. Angiogenic response to VEGF was quantified as the percent green fluorescent area visible under high power magnification (100X). Figure 19F-G shows angiogenesis was initiated in nude mice by subcutaneous injection of 400 μl growth factor reduced matrigel supplemented with 400 ng/ml of bFGF containing (F) 200 μg function blocking rat anti-integrin α4β1 (PS/2) or isotype-matched control antibodies (rat anti-integrin β2) and Figure 19G shows using 50 μM EILDV or EILEV peptides. Fifteen minutes prior to sacrifice on day 5, mice were injected intravenously with endothelial specific lectin, Bandeira simplifolia-FITC. Matrigel plugs were homogenized in RIPA buffer and fluorescence intensity determined.

EXAMPLE 15

Additional data herein is shown in Figure 20. Figure 20A shows cytofluorescence analysis of ECs, EPCs, and fibroblasts for UEA-1 lectin binding and uptake of DiI-acetylated LDL. Figure 20B shows adhesion of purified EPCs to plastic plates coated with 5 μg/ml fibronectin, CS-1 fibronectin, vitronectin and collagen. Figure 20C shows migration of purified EPCs on 8 μm pore transwells coated with 5 μg/ml fibronectin, CS-1 fibronectin, vitronectin and collagen, and Figure 20D shows adhesion of purified EPCs on plastic plates coated with 5 μg/ml vitronectin in the presence of medium, anti-α4β1 (HP1/2), anti-αvβ3 (LM609), anti-αvβ5 (P1F6), or anti-α5β1 (P1F6).

EXAMPLE 16

The following are some exemplary materials and methods that may be useful in the invention, particularly in Examples 17-24 and Figures 33-36. Statistical significance was determined using Student's t-test.

A. Stem cell isolation:

3.7 X 10^9 mononuclear cells were purified by Histopaque gradient centrifugation from

6 units of human buffy coats from the San Diego Blood Bank. CD34 cell isolation was performed by positive selection over two anti-CD34 columns using kits from Miltenyi Biotech (Auburn, CA). The yield of CD34+ cells was $3X10^6$ at a purity of 89% as assessed by FACs analysis.

B. Intravital microscopy

Stem cells were labeled with 5-and-6-4-chloromethylbenzoylamino-tetramethyl-rhodamine (CMTMR, Invitrogen, Carlsbad, CA) in culture medium for 15 minutes on ice and washed. $1X10^6$ labeled stem cells were intravenously injected into mice with N202 syngeneic GFP expressing tumor spheroids grown on transplanted mammary fat pad under transparent dorsal skinfold chambers. Animals were sedated (15-20 minutes) while *in vivo* fluorescence microscopy was performed using a Mikron Instrument Microscope (Mikron Instrument, San Diego, CA) equipped with epi-illuminator and video-triggered stroboscopic illumination from a xenon arc (MV-7600, EG&G, Salem, MA). A silicon intensified target camera (SIT68, Dage-MTI, Michigan City, IN) is attached to the microscope. A Hamamatsu image processor (Argus 20) with firmware version 2.50 (Hamamatsu Photonic System, USA) is used for image enhancement and to capture images to a computer. A Zeiss Achroplan 20X/0.5 W objective 10/0.22 was used to capture images.

C. FACs analysis

FACs analysis was performed at the UCSD Cancer Center Core facility. Expression of integrin $\alpha4\beta1$, CD34 and CD133 on stem cells was analyzed by two color fluorescence using PE-conjugated mouse anti-human $\alpha4\beta1$ (HP2/1, Chemicon International, Temecula, CA), FITC- and PE-conjugated mouse anti-human CD34 (AC136, Miltenyi Biotech, Auburn, CA), and PE-conjugated CD133 (AC133/1, Miltenyi Biotech, Auburn, CA), CD31 (HEC7, Pierce). Expression of VCAM on ECs was determined with P8B1 (Chemicon International, Temecula, CA).

D. Immunohistochemistry

Cryosections were fixed in cold acetone for 2 minutes, air dried and rehydrated in phosphate buffered saline (PBS) for 5 minutes. Slides were washed in 0.05-0.1% Triton X-100 in PBS for 2 minutes, incubated in 5% Bovine Serum Albumin in PBS overnight at 4°C and in primary antibody (5-10 μg/ml) for 2 hours RT, washed three times in PBS and incubated in secondary antibody at 1 μg/ml for 1 hour RT. Slides were washed three times in PBS, stained with DAPI and coverslips mounted. Primary antibodies were: fibronectin (TV-1, Chemicon), anti-mouse VCAM (M/K-2 from Chemicon), anti-pan species VCAM (H-276, sc-8304 from Santa Cruz), and anti-mouse CD31 (MEC 13.3 from Pharmingen).

E. Adhesion assays

Adhesion assays were performed on plastic 48 well plates coated with 5 μg/ml of recombinant H120 CS-1 fibronectin (from Martin J. Humphries, University of Birmingham, UK) as described (Kim et al. (2000) Am. J. Pathol.156, 1345-1362). Stem cells were incubated on coated plates for 30 minutes in the presence of 25μg/ml anti-α4β1_(HP2/1) or anti-αvβ5 (P1F6, from Dr. David Cheresh, the Scripps Research Institute). CMTMR labeled stem cells were incubated in HEPES buffered serum free culture medium in the presence of 25 μg/ml HP2/1 or P1F6 on HUVEC monolayers for 60 minutes at 37°C. Unbound cells were removed by washing gently with PBS. Cells were fixed in 3.7% parafomaldeyde. Representative fields were photographed at 200X and the number of cells adhering per field was quantified in five representative fields per treatment condition.

F. Adoptive Transfer tumor studies

$3X10^6$ CMTMR labeled stem cells were incubated in saline, 50 μg/ml of control antibody (LM609, anti-human αvβ3) or anti-human a4β1 (HP2/1, a gift from Roy Lobb, Biogen or 9F10, Becton-Dickinson, San Diego, CA). The cells were incubated with antibodies on ice for 30 minutes before injecting into nude mice bearing N202 or Lewis lung carcinoma tumors. After one hour, animals were sacrificed. Tumors plus surrounding connective tissue were excised and cryopreserved (n=6).

Alternatively, lineage negative (Lin-) cells were isolated from the bone marrow of EGFP mice by negative immune selection as previously described (Otani et al. (2002) Nat. Med. 8, 1004-1010) Cells were injected into nude mice bearing 0.5 cm Lewis lung carcinoma tumors. Animals were treated for the following five days with saline, control antibody (anti-CD11b) or anti-murine α4β1antibody (PS/2). After five days, animals were sacrificed. Tumors plus surrounding connective tissue were excised and cryopreserved (n=6).

G. Bone marrow transplantation

Bone marrow from FVB/N-Tie2LacZ mice was transplanted into irradiated FVB/N mice. After 12 weeks, mice were injected with 400μl growth factor reduced Matrigel supplemented with 400 ng/ml of bFGF or VEGF and treated on day 1 and 3 by i.v. injection of 200μg/mouse rat anti-mouse of α4β1 antibody (low endotoxin PS/2, a kind gift from Biogen) or rat-anti-mouse β2 integrin (low endotoxin M1/70, Becton-Dickinson, San Diego, CA). Plugs were excised after 5 days (n=8). Studies were performed twice. Cryosections were incubated in X-gal or immunostained with rabbit anti-beta galactosidase and rat anti-murine CD31 (MEC13.3, Becton-Dickinson, San Diego, CA). Positive vessels were quantified at 200X in 10 randomly selected microscopic fields.

EXAMPLE 17

Stem cells home selectively to neovasculature

To understand how stem cells home to the neovasculature, we employed real time-intravital microscopy to study the movement of stem cells transplanted into mice with breast carcinomas. Human CD34+ stem cells were labeled with a red fluorescent cell tracking dye and were injected into the circulation of nude mice that had been implanted with murine breast carcinoma spheroids on mammary fat pads under dorsal skinfold chambers (Figure 33a). Intravital microscopy was performed immediately thereafter to track stem cell homing to the tumor. Tumors and associated non-fluorescent blood vessels were visible (Figure 33b), enabling us to evaluate cell attachment within the vasculature. Circulating fluorescent cells were evident in both the central and peripheral tumor vasculature but they arrested only in blood vessels at the tumor periphery (Figure 33c-d). In contrast, stem cells rarely arrested in the tumor center (Figure 33c-d), or in other organs. Postmortem analysis of tumors by fluorescence microscopy confirmed that stem cells (red, arrowheads) arrested only in the tumor peripheral vasculature, identified by anti-CD31 immunostaining (green, arrows), or extravasated into the neighboring tissue (Figure 33e). These studies indicate that stem cells home selectively to the growing peripheral tumor vasculature and suggest that specific cell attachment mechanisms may play a role in this homing response.

EXAMPLE 18

Stem cells express integrin $\alpha 4\beta 1$

To determine how stem cells arrest in peripheral vasculature, we examined the roles of cell adhesion molecules in stem cell homing. Circulating cells such as lymphocytes utilize integrin $\alpha 4\beta 1$ to arrest on the endothelium and to extravasate from the circulation (Guan et al. (2990) Cell 60, 53-61; and Elices et al. (1990) Cell 60, 577-584), while hematopoietic precursor cells use $\alpha 4\beta 1$ to adhere to bone marrow endothelium (Simmons et al. (1992) Blood. 80, 388-395; Papayannopoulou et al. (2001) Blood 98, 2403-2411; Craddock et al. (1997) Blood 90, 4779-4788; Miyake et al. (1991) J. Cell Biol.114, 557-565). To evaluate a role for $\alpha 4\beta 1$ in stem cell homing, we examined the expression of $\alpha 4\beta 1$ on circulating stem cells by FACs analysis. We found that the large majority of CD34+ cells express $\alpha 4\beta 1$ and that substantially all of the CD34+CD133+ subset, which can differentiate into endothelium (Peichev et al. (2000) Blood 95, 952-958), express integrin $\alpha 4\beta 1$ (Figure 34a).

EXAMPLE 19

Integrin $\alpha 4\beta 1$ is a functionally active receptor on stem cells

Since integrins on circulating cells are often maintained in an inactive or low affinity state (Bartolome et al. (2003) Mol. Biol. Cell 14, 54-66), we next determined whether $\alpha 4\beta 1$

on stem cells is functionally active. Integrin α4β1 is a receptor for cellular fibronectin (CS-1 fibronectin) (Elices et al. (1994) J. Clin. Invest. 93, 405-416) and for VCAM, an immunoglobulin superfamily molecule that is expressed on endothelium in inflamed tissues (Elices et al. (1990) Cell 60, 577-584). Stem cells readily attached to CS-1 fibronectin coated plates; this adhesion was blocked by anti-α4β1, but not control (anti-αvβ5) antibodies (Figure 34b). These results indicate that integrin α4β1 is a functionally active receptor on many stem cells.

EXAMPLE 20

Integrin α4β1 Interaction with VCAM and/or fibronectin mediates attachment of stem cells to endothelial cells *in vitro*

To determine whether stem cells can attach to endothelial cells (ECs) in an α4β1 dependent manner, we plated fluorescently labeled stem cells on confluent EC monolayers, which express the α4β1 ligand VCAM (Figure 34c). Stem cells bound strongly to ECs (Figure 34d-e). This adhesion was blocked by antibody antagonists of α4β1 but not by control antibodies (anti-αvβ5) (Figure 34d-e). Attachment was also blocked by recombinant soluble VCAM, a competitive inhibitor of integrin α4β1 function. These studies demonstrate that α4β1 can mediate the attachment of stem cells to ECs *in vitro* and suggest the possibility that α4-VCAM or α4-fibronectin interactions can promote stem cell adhesion to the vasculature.

EXAMPLE 21

Neovasculature cells express Integrin α4β1 ligands VCAM and fibronectin *in vitro*

We next examined whether tissues undergoing neovascularization express the α4β1 ligands VCAM and cellular fibronectin by examining mouse breast carcinomas or normal tissue for these molecules. Both molecules (green) are expressed in tumor endothelium (red, Figure 35a), at much greater levels in the tumor periphery than in its center (Figure 35a). These ligands are rarely expressed by normal endothelium, although fibronectin was occasionally observed around large vessels (Figure 35a). These results demonstrate that the α4β1 ligands VCAM and fibronectin are in precisely the right location to promote the adhesion of α4β1+ stem cells.

EXAMPLE 22

Integrin α4β1-antibody inhibits stem cell migration to neovasculature *in vivo*

To determine if α4β1 mediates the attachment of stem cells to growing blood vessels *in vivo,* fluorescently labeled stem cells were introduced by tail vein injection into nude mice with established murine breast carcinoma (N202) or Lewis lung carcinoma (LLC) tumors. Tissues were removed for analysis within one hour of cell injection. Stem cells (red) arrested

in or extravasated near the vessels (green) of both tumor types (Figure 35b). Strikingly, when stem cells were co-injected with function-blocking anti-human $\alpha4\beta1$ antibodies, they were unable to arrest in the vasculature of either tumor type (Figure 35b-d). In contrast, saline or control antibodies had minimal effect on stem cell arrest and adhesion (Fig 35b-d). Although stem cells homed to the tumor vasculature, they did not home to adjacent normal tissues or to other organs such as lung. These studies indicate that $\alpha4\beta1$ regulates homing of stem cells to tumor neovasculature. These results discount nonspecific homing of cells to leaky tumor vessels, because stem cells do not lodge in central tumor vessels and antagonists of specific receptors block their adhesion in vessels.

EXAMPLE 23

Integrin $\alpha4\beta1$-antibody inhibits stem cell differentiation into vascular endothelium *in vivo*

To determine whether $\alpha4\beta1$ promotes stem cell homing *and* subsequent participation in blood vessel formation *in vivo*, we injected lineage negative (Lin-) bone marrow derived cells from EGFP (enhanced green fluorescent protein) mice[6] into animals with LLC tumors in the presence or absence of $\alpha4\beta1$ antagonists and control antibodies. We found that after five days *in vivo*, EGFP+ cells in control treated animals had homed to tumors in significant numbers (arrowheads) and formed EGFP+ blood vessels (arrows, Figure 36a-b). In contrast, few EGFP+ cells were observed in tumors of anti-$\alpha4\beta1$ treated mice and no EGFP+ vessels were observed (Figure 36a-b). These studies indicate that prevention of stem cell homing to the tumor vasculature inhibits their differentiation into vascular endothelium.

EXAMPLE 24

Integrin $\alpha4\beta1$-antibody inhibits bone marrow stem cell migration to neovasculature *in vivo*

The above data suggested that integrin $\alpha4\beta1$ mediates the homing of stem cells arising directly from the bone marrow to tumors. To evaluate this, mice were transplanted with bone marrow from Tie2Lac Z mice. In these mice, bone marrow derived cells that differentiate into endothelium *in vivo* express beta-galactosidase under the control of the promoter of endothelial protein Tie2. Angiogenesis was stimulated in these mice by implantation of growth factor reduced Matrigel saturated with VEGF or bFGF. These growth factors induced an angiogenic response as well as the homing of beta galactosidase positive cells (Figure 36c-d). Treatment of mice with anti-$\alpha4\beta1$, but not anti-$\beta2$ integrin, antibodies, completely blocked the incorporation of beta-galactosidase positive cells into Matrigel (Figure 36c-d). In control-treated animals, a majority of the beta-galactosidase positive cells incorporated into the neovasculature (arrows), as determined by anti-CD31 (red) and anti-beta

galactosidase (green) immunostaining (Figure 36e-f). Importantly, antagonists of α4β1 completely blocked this incorporation (Figure 36e-f). Taken together, these studies indicate that α4β1, but not β2 integrin, potentiates stem cell trafficking by promoting their attachment to the neovasculature in remodeling tissues.